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UTILIZATION AS RF-ANTENNAS OF LIVE AND OF LIFELESS STRUCTURES IN NATURAL AND IN MAN MADE JUNGLES

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TECHNICAL REPORT ECOM-4133

UTILIZATION AS RF-ANTENNAS OF LIVE AND OF LIFELESS STRUCTURES IN NATURAL AND IN MAN MADE JUNGLES

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ABSTRACT

Natural forest trees, man-planted shade trees, metal lantern poles and building structures were utilized as efficient HF radio antennas with the aid of Hybrid Electromagnetic Antenna Couplers (HEMAC's). The performance of live trees and of inanimate metal structures as antennas is compared with the performance of conventional HF whip and dipole antennas. Similar practical data are given on the LF radio signal emission capabilities of huge steel-concrete buildings and on LF radio signal diffusion via electrical power and water distribution systems in suburban areas.

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1. INTRODUCTION

The capability of vegetation and of trees to serve as radio antennas has been recognized as early as 1904 by Major George O. Squire of the US Army Signal Corps.[1] M. G. Squire's ideas of using trees as radio antennas have been realized in practice with the aid of a flexible toroid shaped Hybrid Electro-Magnetic Antenna Coupler device called a HEMAC.[2] As a result of field experiments and radio transmission measurements which were carried out with conventional hardware antennas and with HEMAC coupled trees in tropical jungle forests in the Panama Canal Zone, it became evident that jungle trees serving as MF and HF antennas are able to overcome the obstructing effects of jungle vegetation relative to conventional antennas on RF communications.[3]

Furthermore, measurements of MF and of HF radiation patterns from forest trees in the Ft. Monmouth, N.J. area[4] and in the Lebanon, N.J. State Forest[5] revealed that in particular the HF radiation pattern directivities are caused by "dominant natural tree loops" that is by the parasitic array-like interaction between the HEMAC coupled tree and nearby neighbor trees. However, as stated in the first part of this report, the control of the directivity of RF emissions from forest trees need not be left to orientations of the natural dominant tree loops at a chosen transmitter (XMTR) location in the forest; the directivity of RF signal emissions via forest trees can be controlled by the radio operator with the aid of phased HEMAC coupled tree arrays. Yet, whereas control over the directivity of the RF radiation becomes a matter of human effort, the control over the range of applicable practical radio frequencies remains a function of the material and structural heterogeneity and anisotropy of the forest vegetation. Corresponding implications with regard to matching conventional radio transmitters to the impedances of forest trees and the surrounding underbrush vegetation are discussed in the second part of this report. In the third part, the search for practical upper frequency limits is pursued indirectly by comparing the performance of trees as radiating antennas with that of metal lantern poles of comparable dimensions. This comparison of live structures of natural jungles with lifeless structures of urban jungles provides the transition to the fourth part which describes the utilization of steel and concrete structures, buildings, water and power lines etc., for radiation and transmission of RF signals in "urban jungles". Emphasis is placed here on the distinction between RF radiation from buildings and RF diffusion inside buildings and on the corresponding methods and means for RF signal emission and reception.

2. DISCUSSION

A. Control of Directivity of RF Signal Radiation from a HEMAC Coupled Forest Tree Array.

The pair of forest trees which served as transmitting antenna and which will be referred to as twin tree array is shown in Fig. 1. The tree trunks are four meters apart and have a circumference of 1.85 and 2.4 meters measured at 1.5 meters above ground. A close-up view of the match box and HEMAC toroid circuit on one of the trees is seen in Fig. 2. A picture of the XMTR setup in a shelter in the vicinity of the trees is given in Fig. 3.

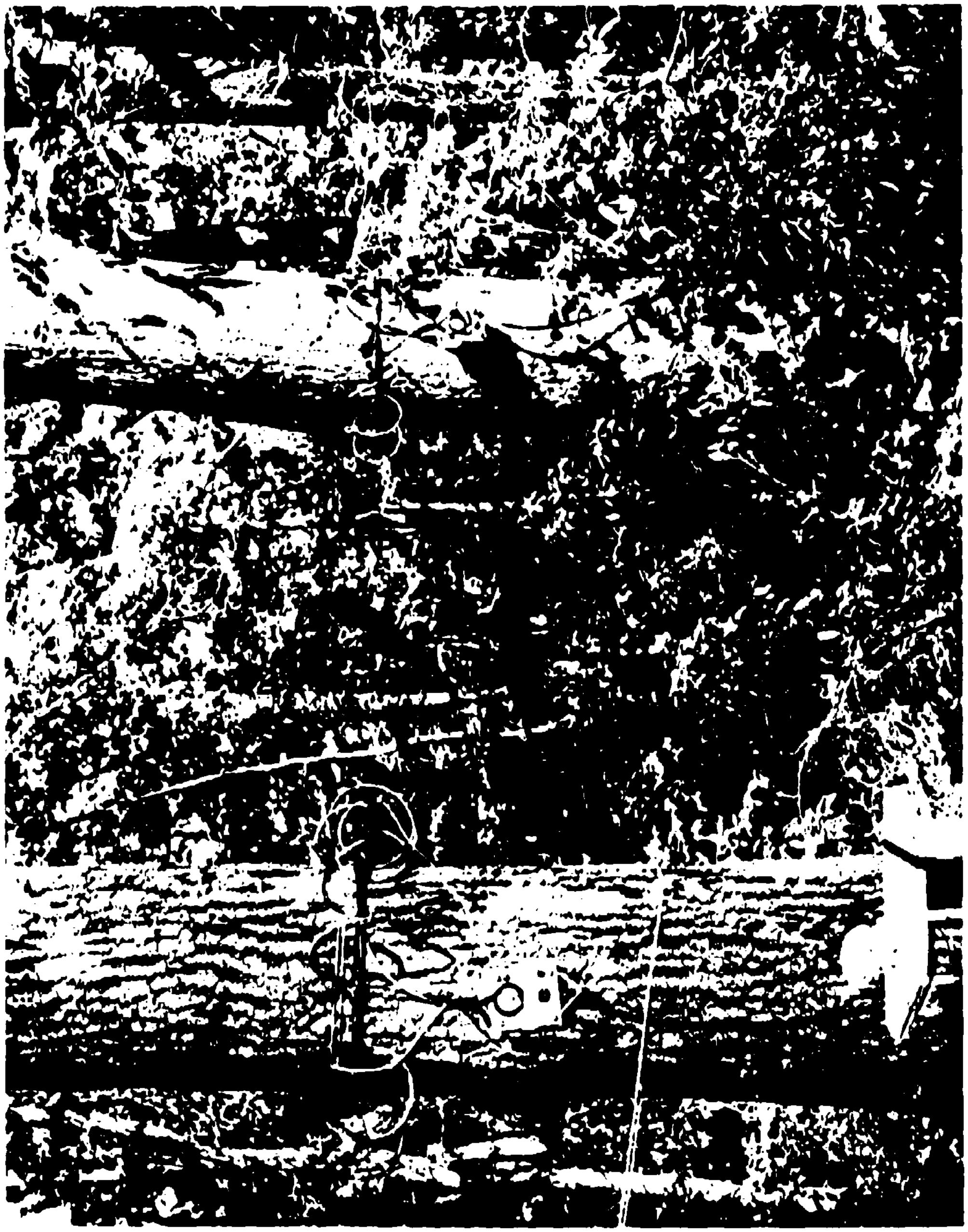

Fig. 1 HEMAC Toroid Coupled Tree Array
Wayside Test Area
Sept., Oct. 1972

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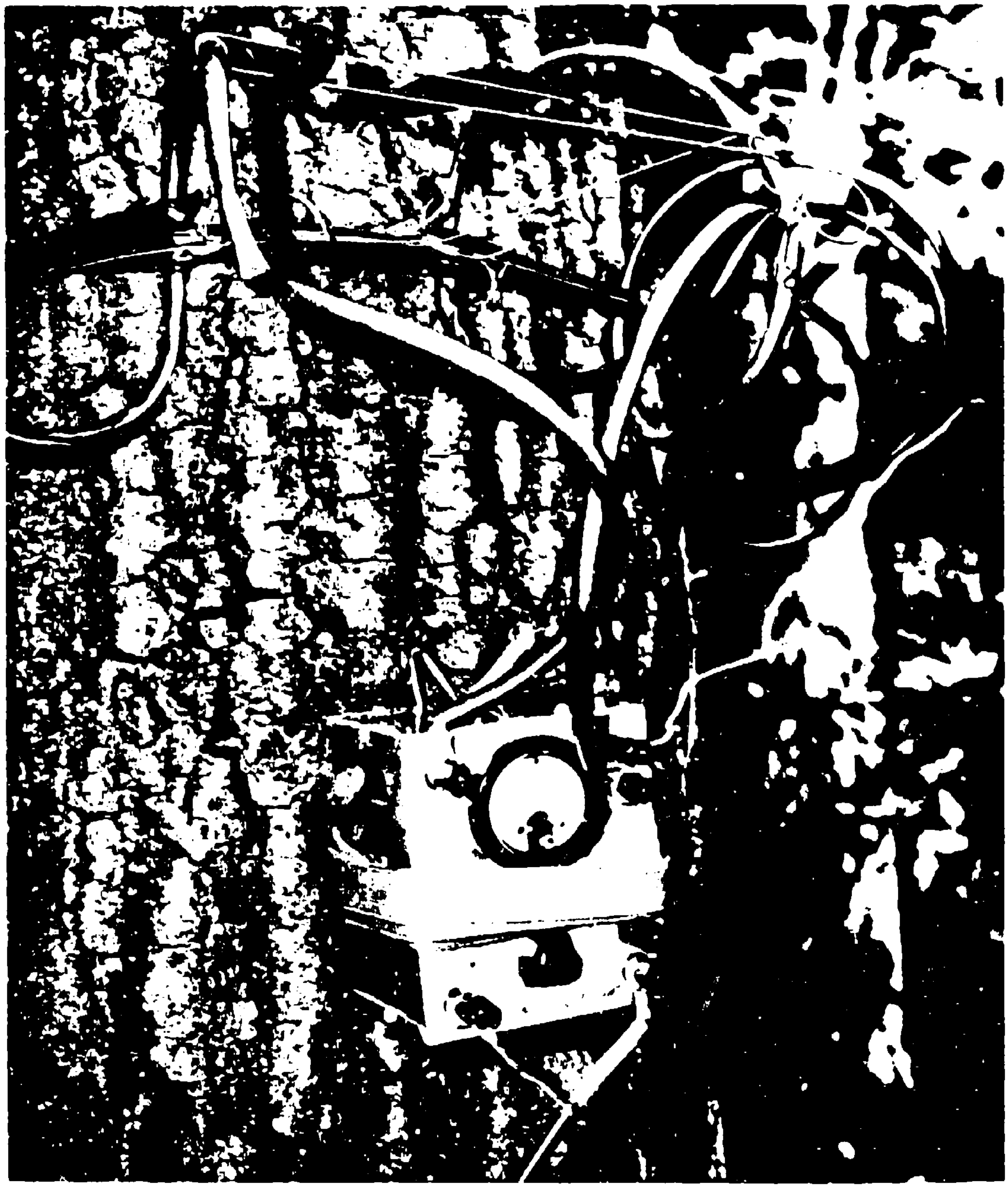

Fig. 2 HEMAC Coupled Tree Circuit
(Close-up View)
Wayside Test Area
Sept., Oct. 1972

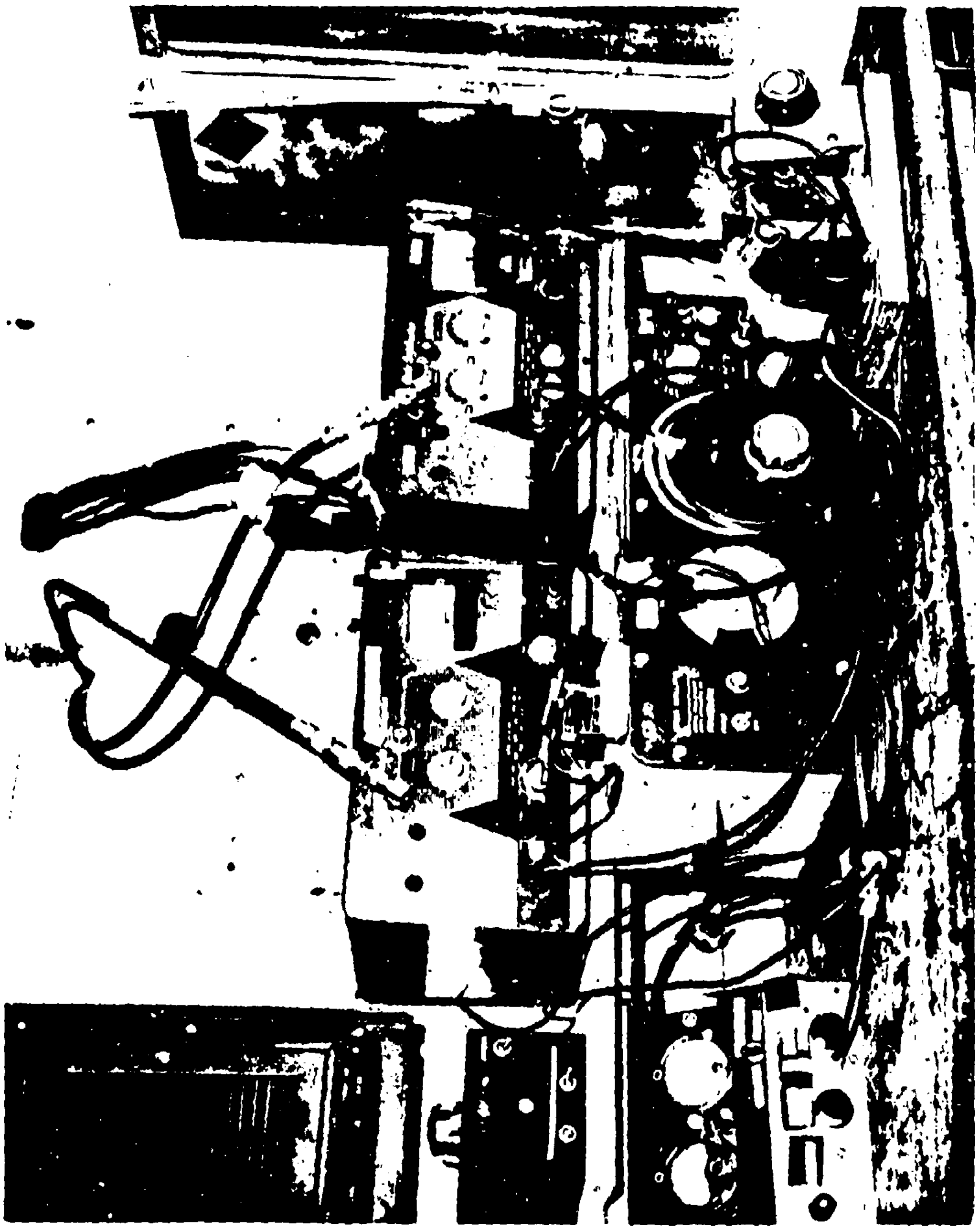

Fig. 3 Transmitter Setup for Twin Tree
Array
Wayside Test Area
Sept., Oct. 1972

The block diagram of the XMTR circuit is shown in Fig. 4. The HEMAC coupled trees are connected with the XMTR setup in the shelter by nine and fifteen meters long coaxial cables. The XMTR setup consists of a pair of Globe Amateur Radio XMTR Sets which are operated in the AM and CW mode. The VFO input of the Globe XMTR Set No. 1 is connected via a capacitive voltage divider to the output of a crystal (XTAL) controlled oscillator. The input of the other Globe XMTR Set No. 2 is connected to the XTAL controlled oscillator via a delay line made from a 36 meter long RG-58 cable with taps at four meter spacings. The phase difference between the VFO input signals of Globe XMTR Set No. 1 and No. 2 is adjusted in steps by plugging into different taps of the delay line; smooth fine adjustment of the phase is obtained with a tuning capacitor which can be connected to the dummy load end of the delay line or across an unused tap of the delay line. The phase differences of the resultant XMTR output voltages were displayed on an oscilloscope in form Lissajou patterns. For this purpose, the x and the y inputs of the oscilloscope were coupled to the connections of the No. 1 and No. 2 tree feed cables and the No. 1 and No. 2 Globe XMTR outputs. The maximum CW power output from these transmitters was determined to be 12 and 16 watts. Radiation patterns were measured at a frequency of 4.650 MHz with a vertical 5 foot long whip antenna that was mounted on a truck shelter and connected via RG-58 cable to the untuned high impedance input of a BK-2007 Heterodyne Millivolt Meter. The whip equipped truck and the BK-2007 meter are shown in Figures 5 and 6. On the map in Fig. 7 are marked the XMTR location in the Wayside N.J. test area and the receiver location 1 to 12 along a circle of a 3 mile radius. The results of the radiation pattern measurements are shown graphically in Figures 8 to 10. In Fig. 8 are plotted the received signal plus noise levels and the noise levels at the receiver locations 1 to 12. The signal plus noise level radiation patterns are given for the following operating condition of the XMTR setup. (1) XMTR No. 1 feeding tree No. 1 turned on the XMTR No. 2 turned off. (2) XMTR No. 2 feeding tree No. 2 turned on and XMTR No. 1 turned off. Under these conditions the SWR values on the feed cables were 1.1 and 1.0. In this connection, it is necessary to point out that the above SWR amounts to matching to load impedances, which include the parasitic loading of XMTR No. 1 by tree No. 2 and vice versa of XMTR No. 2 by tree No. 1. Next refer to the radiation patterns in Figures 9 and 10 with both the No. 1 and No. 2 XMTR turned on and with different phase delays of the VFO input signal for XMTR No. 2 relative to that of XMTR No. 1. Evidently by changing the phase of the corresponding RF currents in the HEMAC coupled tree circuits the radiation maxima from the twin tree array are steered into different geographic directions to the northeast for $\Delta\varphi = 0^{\circ}$, and to the east and northwest for $\Delta\varphi = 90^{\circ}$ and 180°. However, due to the mutual coupling between the two trees, phase changes effect also changes of the SWR values. For this particular forest tree array setup, SWR values ranged up to 3 to 1. The corresponding variations in the individual HEMAC load impedance are also reflected by the variations of HEMAC currents as functions of XMTR phasing.

Hence without resort to more sophisticated phasing and tuning circuitry, the gain from the control over the directivity of RF radiation from closely spaced forest tree arrays is partially offset by the inefficient utilization of the available XMTR power. However, the practical usefulness

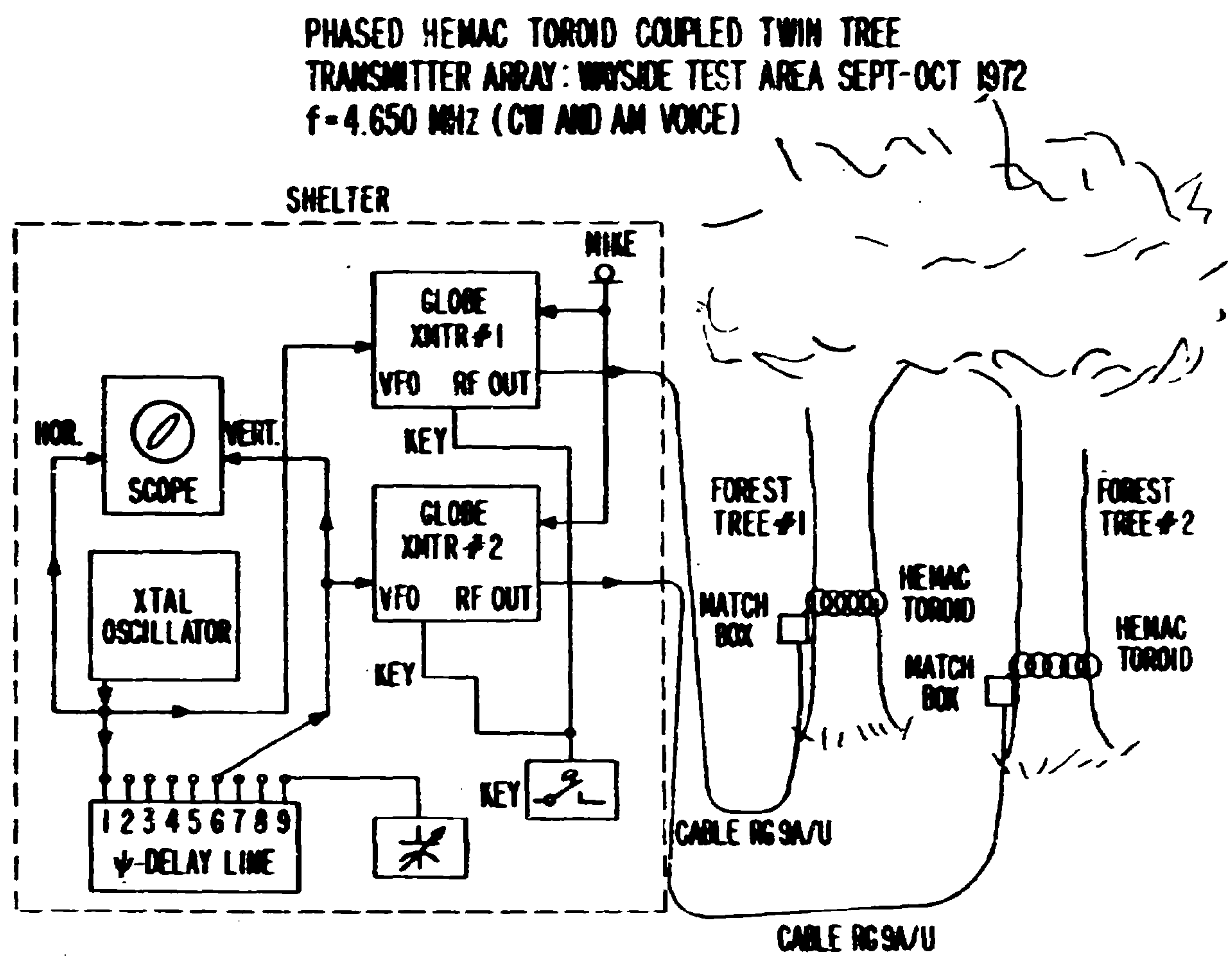

Fig. 4 Phased HEMAC Toroid Coupled Twin Tree Transmitter Array Block Diagram
Wayside Test Area
Sept., Oct. 1972

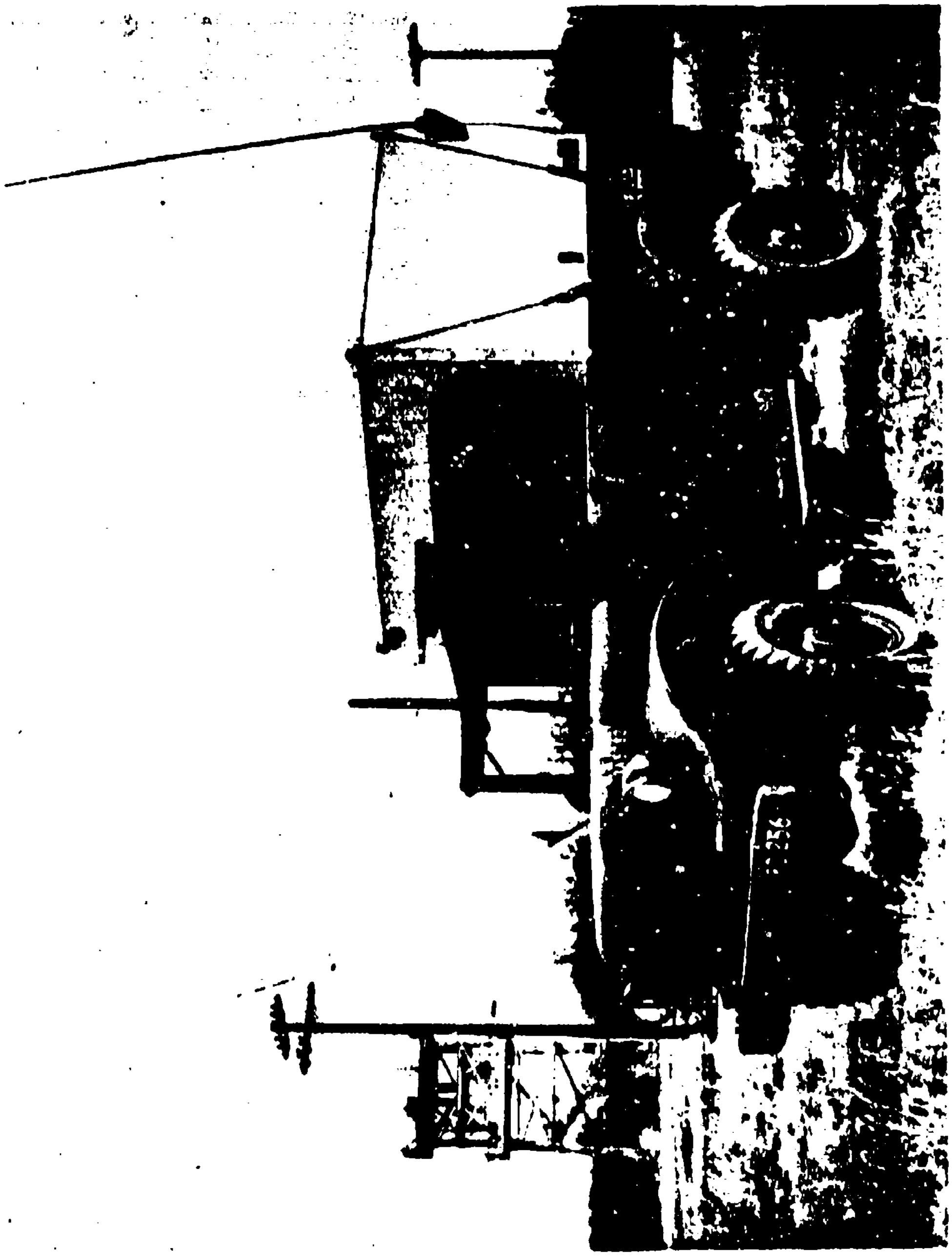

Fig. 5 Whip Equipped Receiver Vehicle

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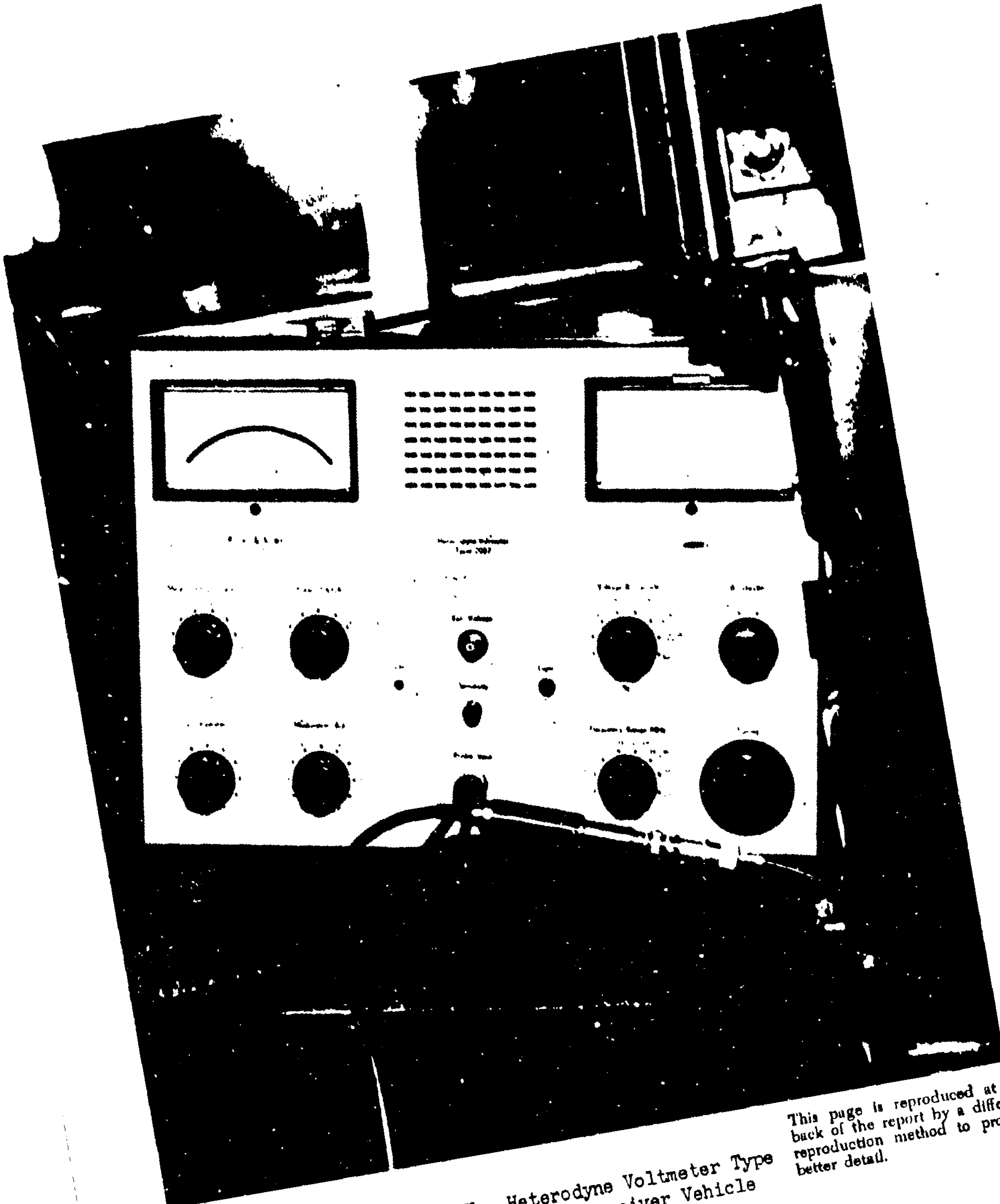

Fig. 6 BK - Heterodyne Voltmeter Type 2007 in the Receiver Vehicle

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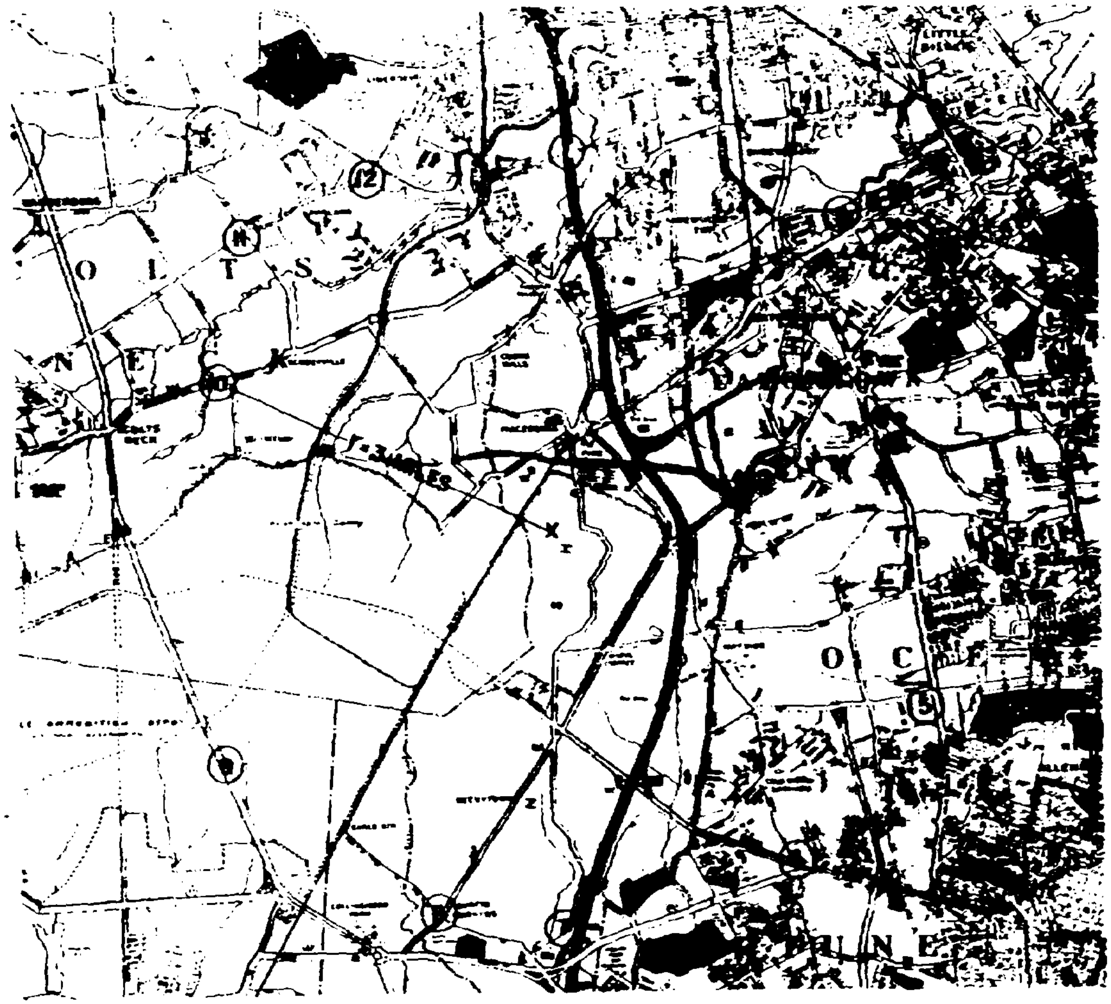


Fig. 7 MAP OF XMTR(X) AND RECEIVER LOCATIONS 1 TO 12 MEASUREMENTS OF RADIATION PATTERNS FROM HEMAC COUPLED TWIN TREE XMTR ARRAY.

OCT. 1972

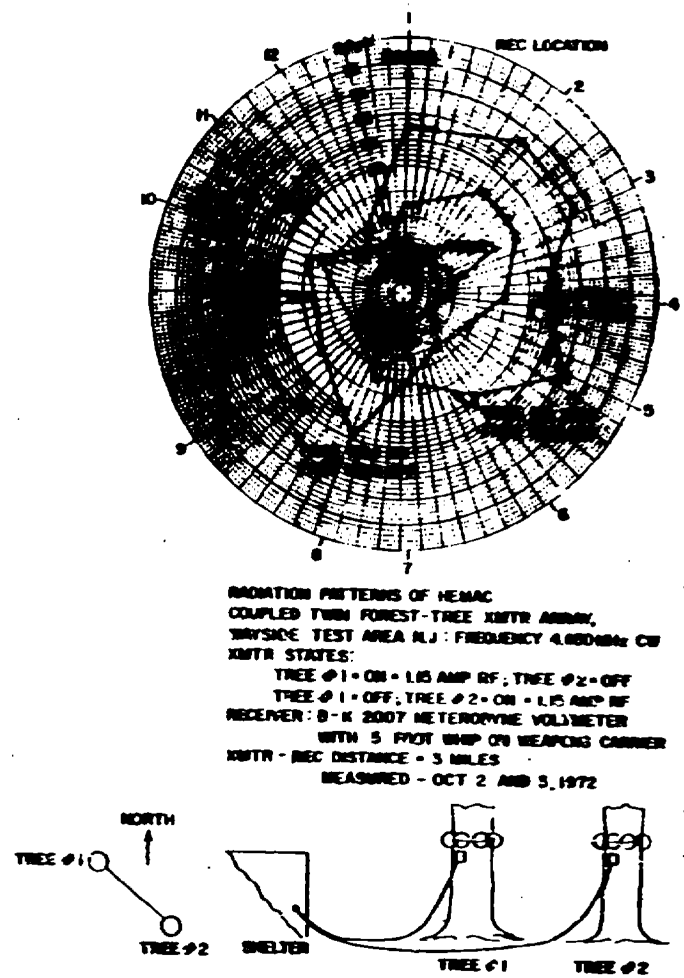


Fig. 8 Radiation Patterns of HEMAC Coupled Twin Forest Tree XMTR Array. (Tree #1 = On, Tree #2 = Off, Tree #1 = Off, Tree #2 = On) Ft. Monmouth Area Oct. 1972

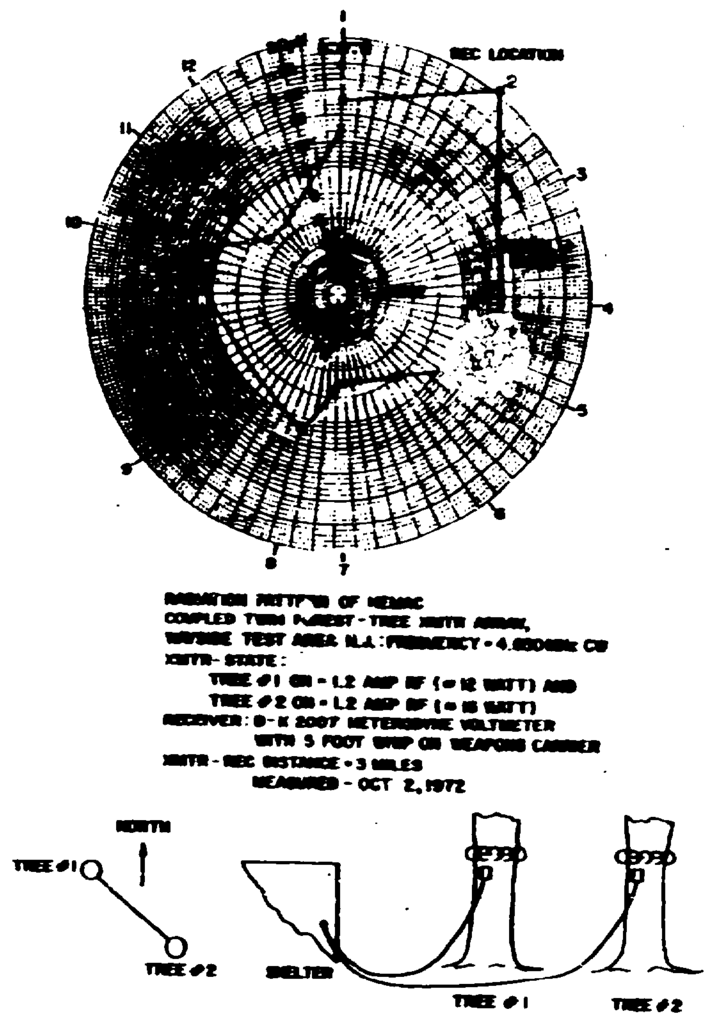


Fig. 9 Radiation Pattern of HEMAC
Coupled Twin Forest Tree XMTR
Array (Tree #1 = On, and Tree #2 = On; $\Delta\gamma = 0^{\circ}$
Ft. Monmouth Area Oct. 1972

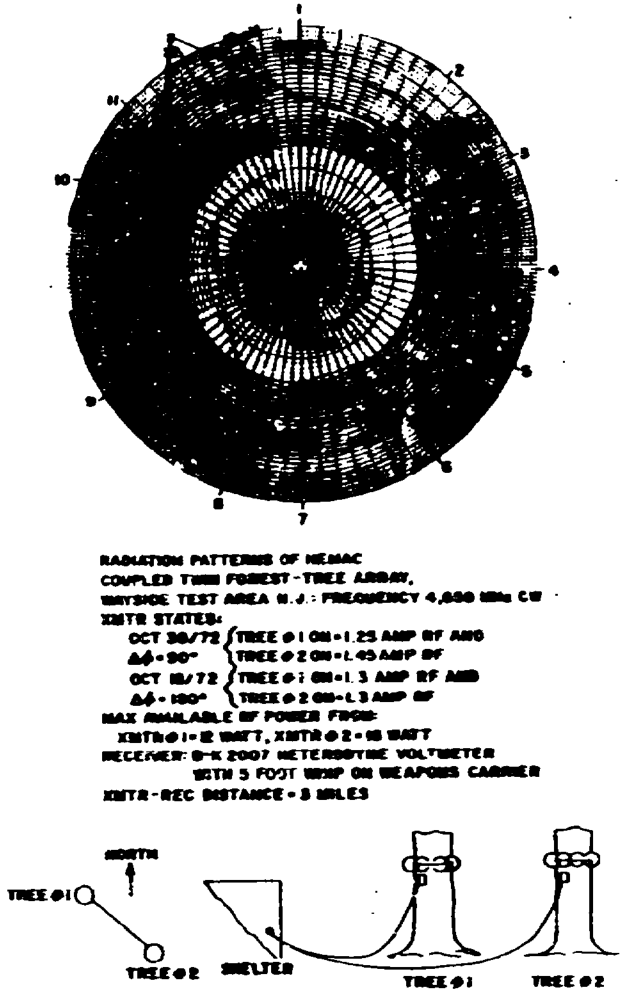


Fig. 10 Radiation Patterns of HEMAC Coupled Twin Forest Tree XMTR Array (Tree #1 = On and Tree #2 = On; $\Delta\varphi$ = 90°, 180°
Ft. Monmouth Area Oct. 1972

of phased forest tree arrays may be judged not only by the directions of the radiation maxima but also by the overall shapes of the radiation patterns including the directions of minima and of nulls and by the data in Figure 11. In Figure 11 is shown the signal plus noise and the noise levels received at station AD2XL in the Evans Area, seven miles to the south, and by whip equipped vehicle at Colts Neck, three miles to the west, from the Wayside Forest XMTR location. These signal plus noise levels are given in connection with the XMTR phasing and the corresponding Lissajou patterns as displayed on the scope. The strong coupling between the trees is reflected by the parasitic current levels of 0.55 and 0.5 Amp RF in the ON-OFF states of the Globe No. 1 and 2 XMTR sets. This kind of mutual coupling becomes much stronger when a pair of HEMAC's is coupled to one and the same tree. Such a HEMAC-tree setup was tried out during initial experiments with tree loops so as to optimize sky wave radiation but this attempt failed because of the strong mutual coupling and resultant difficulties in keeping adequate power match while varying the phasing.

As pointed out before, the mutual coupling between different trees in a forest tree array offsets to some extent the efficient utilization of the available XMTR power; however, considering the overall performance of the twin forest tree array as described by the radiation patterns and the data in Figures 8 to 11 it is evident that the original objectives were realized, in that control over the directivity of RF radiation has been taken from the dominant natural tree loops and handed to the radio operator. Thus we may now turn our attention to other factors that affect the efficiency of operation of forest trees as antennas, namely the HEMAC-Tree load impedances as functions of frequency which are the topic of Section B of the discussion.

B. <u>HEMAC-Tree Load Impedances.</u>

The efficient utilization of forest trees as radio transmitter antennas depends primarily on the ability to match the transmitter output impedance to the input impedances of HEMAC coupled forest trees. Possible solutions of this matching problem depends on whether the transmitter is equipped with variable output impedance controls and whether the XMTR to HEMAC-Tree connection can be made very short in terms of wave length or whether the HEMAC-Tree load circuit impedance must be powered from a source with a fixed output impedance, such as presented by a random length of cable.

In the first case a fixed impedance transformation network can be designed which within certain ranges of frequencies and impedance ratios will provide a satisfactory match between a variable transmitter output circuit and tuned HEMAC-Tree load impedances.[3] In the second case a variable HEMAC-Tree tuning and impedance transformation circuit, referred to in the following as match box, is required.

Typical HEMAC-Tree impedances as functions of frequency which must then be matched to nominal 50 Ohm source impedances are shown in Figures 12 to 14. The resistance R and reactance X versus frequency curves in these figures were measured with a HEMAC on tree No. 1 of the previously

CW AND AM VOICE-4.650 MHz TRANSMISSION TEST DATA FOR A PAIR OF HEMAC COUPLED FOREST TREES LOCATED IN THE WAYSIDE TEST AREA AND SERVING AS PHASED XMTR ANTENNA ARRAY POWERED BY AN XTAL CONTROLLED PAIR OF "GLOBE DSB-100" XMTR SETS.

DATE OF TEST	XMTR STATE GLOBE SET (xx)		PHASE CONTROL (x)				HEMAC CURRENT		RECEIVED SIGNAL AND NOISE LEVELS		RECEIVER LOCATION and INSTRUMENTATION
	No. 1	No. 2	DELAY LINE TAP No.	VAR. CAP. (Cφ)	SCOPE PATTERN	φ (Deg)	TREE No. 1 (Amp)	TREE No. 2 (Amp)	S+N	N	
13 OCT. 72	ON	OFF	8	max	—		1.1	parasitic (a.55)	30 dB	10 dB	CAMP EVANS STATION AD2XL (Bldg. T113) - WIRE ANTENNA AND R390A RADIO RECEIVER
	OFF	ON	8	max	|		parasitic (a.5)	1.0	30 dB	10 dB	
	ON	ON	8	max	O	90°	1.25	1.15	33 dB	10 dB	
	ON	ON	6	2/3	/	0°	1.0	1.45	35 dB	10 dB	
	ON	ON	1	max	\	≈180°	1.15	0.8	28 dB	10 dB	
16 OCT 72	ON	ON	8	max	O	90°	1.0	1.1	7.0 μV	4.0 μV	COLTSNECK N.J. PHALANX AND LAIRD ROAD (LAIRD'S APPLE FARM) - WHIP ANTENNA (6 foot) AND "BK" HETERODYNE VOLTMETER ON WEAPONS CARRIER
	ON	ON	6	2/3	/	0°	1.1	1.3	4.5 μV	4.0 μV	
	ON	ON	1	max	\	≈180°	0.8	1.1	14.0 μV	4.0 μV	
	ON	OFF	1	max	—		0.7	parasitic	6.0 μV	4.0 μV	
	OFF	ON	1	max	|		parasitic	1.15	7.0 μV	4.0 μV	

REMARKS: (x) PHASE of XMTR DRIVE SIGNAL FOR GLOBE No. 2 RELATIVE TO GLOBE No. 1 SET
(xx) AVAILABLE RF OUTPUT POWER ≤ 11 WATT

Fig. 11 CW and AM Voice - 4.650 MHz Transmission Test Data (Twin Tree XMTR-Array - Wayside Area to Station AD2XL Evans Area) Oct. 1972

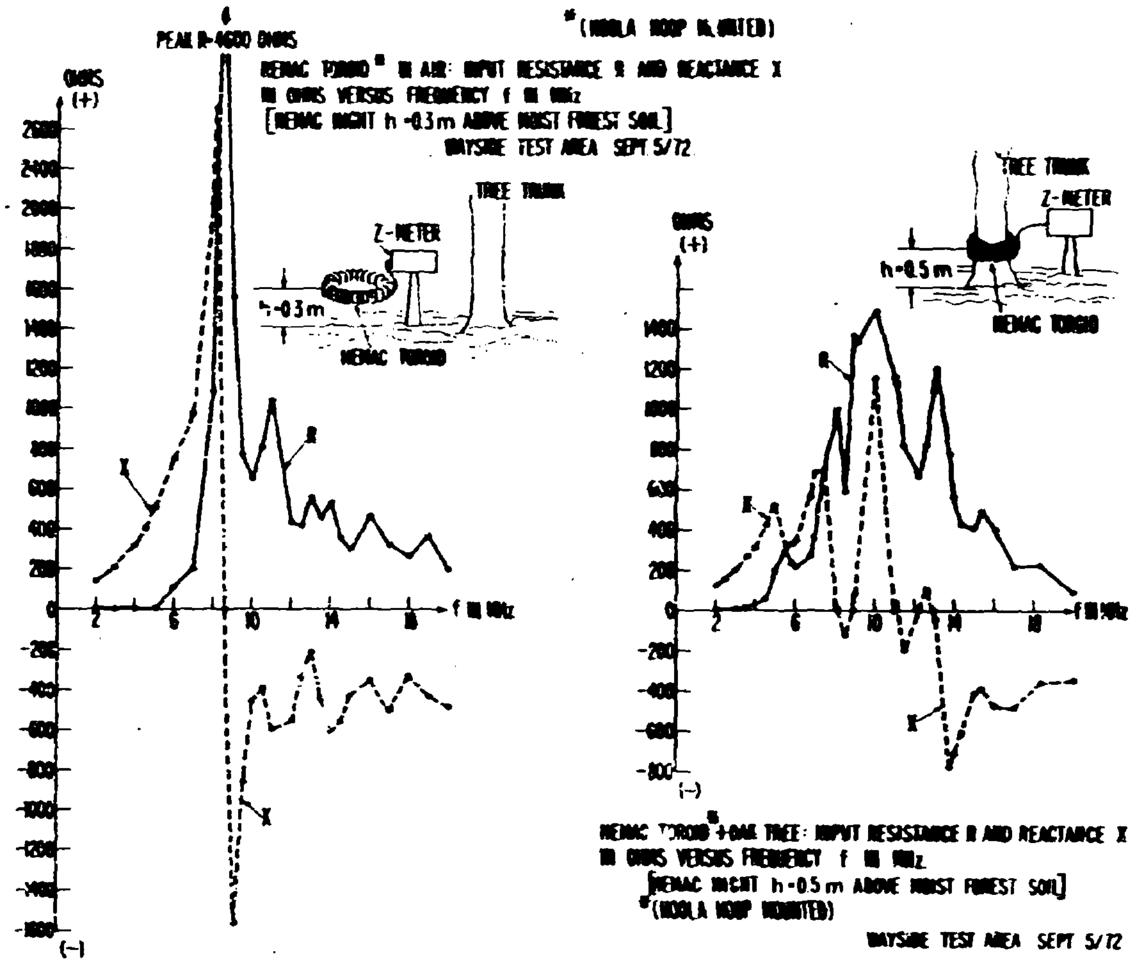


Fig. 12 HEMAC-Toroid Input Resistance
and Reactances (On-Off Tree)
h = .5m
Wayside Test Area Sept. 1972

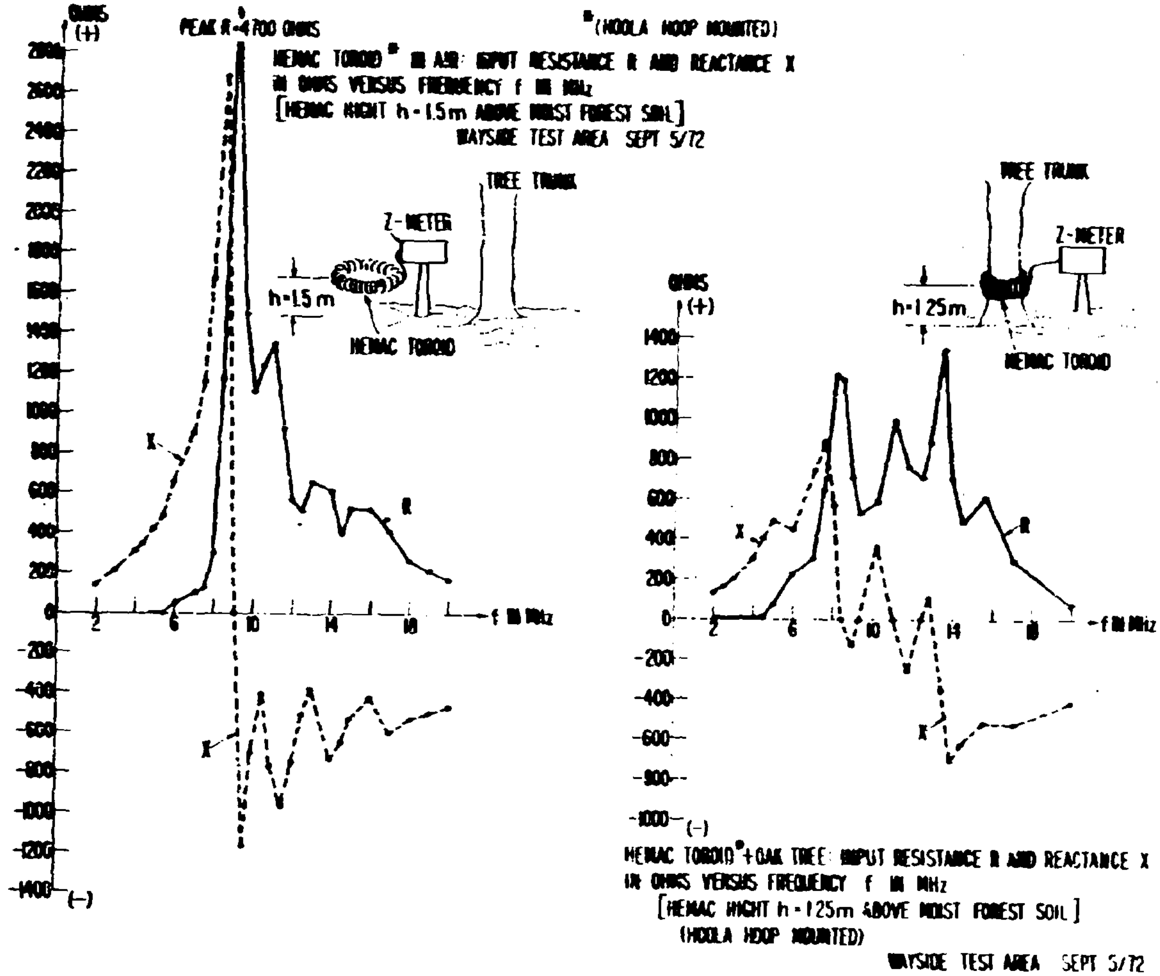


Fig. 13 HEMAC-Toroid Input Resistance
and Reactances (On-Off Tree)
h = 1.25m
Wayside Test Area Sept. 1972

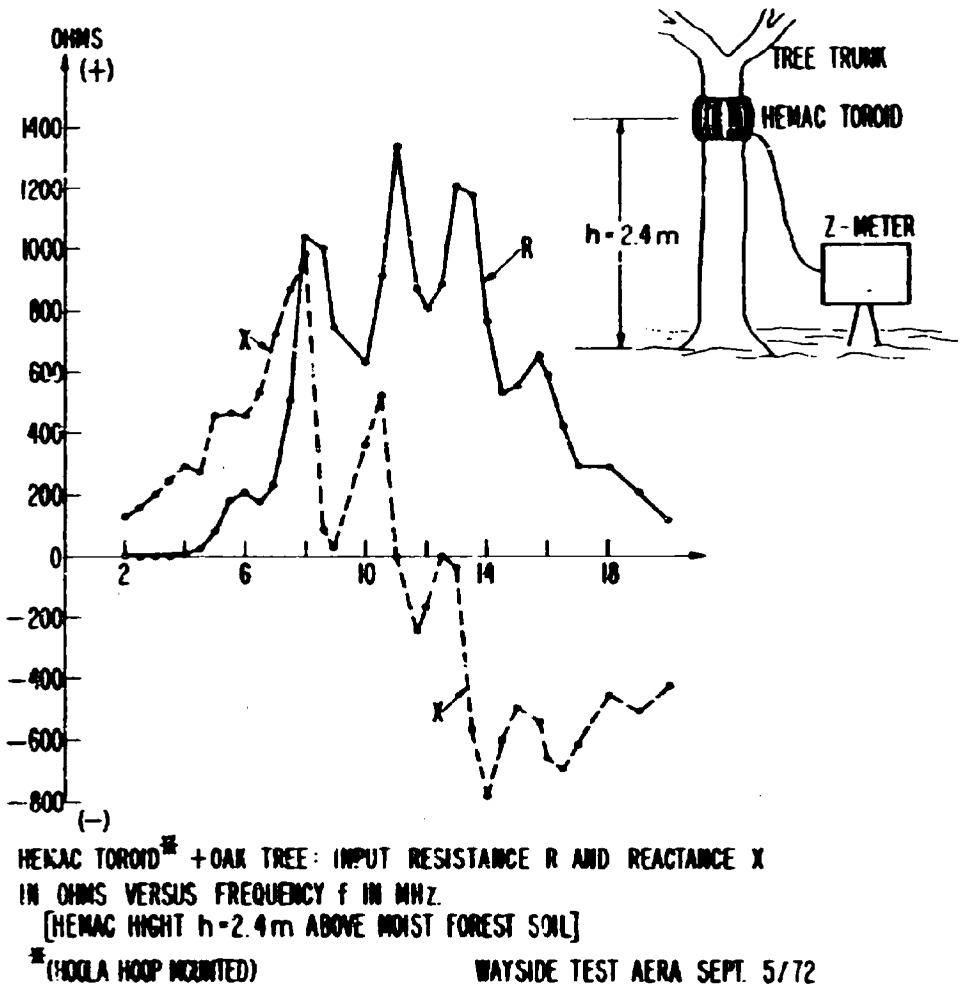
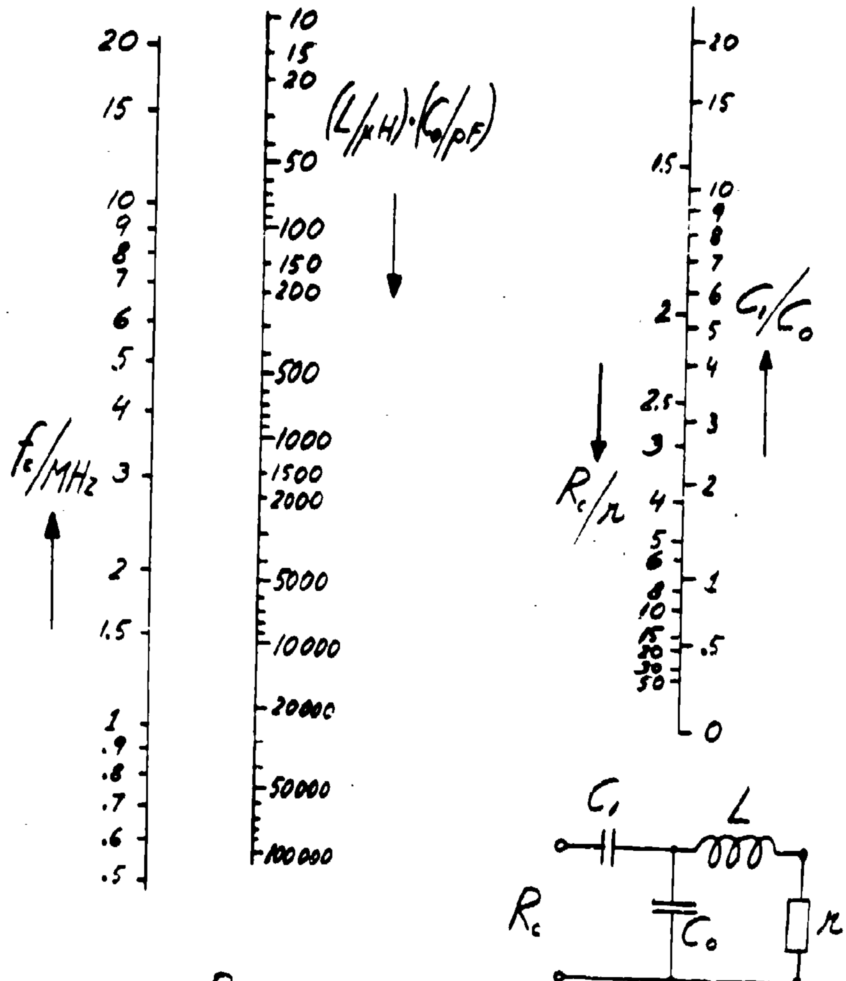


Fig. 14 HEMAC-Toroid Input Resistance
and Reactance (On Tree h = 2.4m)
Wayside Test Area Sept. 1972

described twin tree array. For these measurements, the flexible HEMAC toroid was mounted on a rigid plastic ring to maintain the same shape of the HEMAC when used on and off the tree. Referring to the R and X in Figures 12 and 13 one recognized first of all that HEMAC impedances off the tree in air and on the tree are drastically different. In air above the ground the HEMAC reactance is inductive below and capacitive above the sharp resonance at about 9 MHz. On the tree several transitions between inductive and capacitive regimes occur between 8 MHz and 14 MHz. The corresponding resonances are displayed by the relative maxima of the resistance curves at about 9 MHz, 11 MHz, and 14 MHz. The height above ground of the HEMAC on the tree influences the shape and distribution of the relative maxima of the resistance and of the corresponding zero crossings of the reactance; apparently increasing the height of the HEMAC above ground tends to eliminate the capacitive impedance region around 9 MHz as seen by comparing Figures 12 and 13. The operating frequency range obtained with capacitively tuned matching circuits is then increased accordingly. The peculiar resonances of the HEMAC on the tree in conjunction with the capacitively tuned matching circuit explains the previously observed abrupt decays of radiation from different trees at frequencies between 7 and 11 MHz. Below the frequency of transition from the inductive to the capacitive regime the matching and tuning of HEMAC coupled trees is accomplished with two variable capacitors C_1 and C_0 in accordance with the HEMAC R_c/r matching nomogram in Figure 15. R_c and r refer to respectively the constant source resistance and the HEMAC-Tree load resistance. The optimum matching conditions given by the nomogram correspond to the critically damped resonance mode of the circuit. In practice this optimum match is achieved by maximizing relative power and by minimizing the SWR. For this purpose a simultaneously power and SWR indicating meter has been incorporated into the original HEMAC matching box. Evidence that the tuning of the HEMAC-Tree transmitter circuits requires less skill than tuning of the PRC-74 whip XMTR circuit may be deduced from the input resistance R and reactance X of the PRC-74 whip which are plotted versus frequency in Fig. 16. Furthermore, since the previously mentioned experiments in the Panama Canal Zone and in the Lebanon, N.J. State Forest have shown that in the 60 to 80 meter wave length range the center coil resonated and 2.7 meter long PRC-74 whip can hardly compete with large 20 to 30 meter high forest trees, smaller trees and metal lantern poles were subsequently put to work as antennas at shorter wave lengths; as seen in Figure 17 the poles present to the HEMAC a similar load with fewer resonances. The resultant implications with regard to RF communications in natural jungles of live vegetation and in urban jungles of dead steel and concrete will become evident in Section C.

C. Live Wooden Trees versus Dead Metal Lantern Poles.

The relative dimensions of a typical smaller tree and of a 9 meter high metal lantern pole in relation to the PRC-74 whip antenna are seen in Figures 18 and 19. Close-up views of the PRC-74 Radio Transceiver setups with HEMAC coupled trees and metal lantern poles in the Hexagon-Ft. Monmouth area are shown in Figures 20 to 23. Figure 24 shows a HEMAC PRC-74 transceiver setup on a short wooden pole that protects one of the fire hydrants in the Hexagon yard. A similar setup with the HEMAC on the roof of a jeep is seen in Figure 25. Voice and keyed CW signals emitted from these PRC-74



HEMAC R_c/r MATCHING-TUNING NOMOGRAM

$$f_c = \frac{1}{2\pi\sqrt{L C_0}\sqrt{1+C_1/C_0}} \qquad \frac{R_c}{r} = \frac{1}{\left(1-\frac{1}{1+C_1/C_0}\right)\left(1-\frac{1}{\sqrt{1+C_1/C_0}}\right)}$$

Fig. 15 HEMAC-Toroid R_c/r Matching Tuning Nomogram

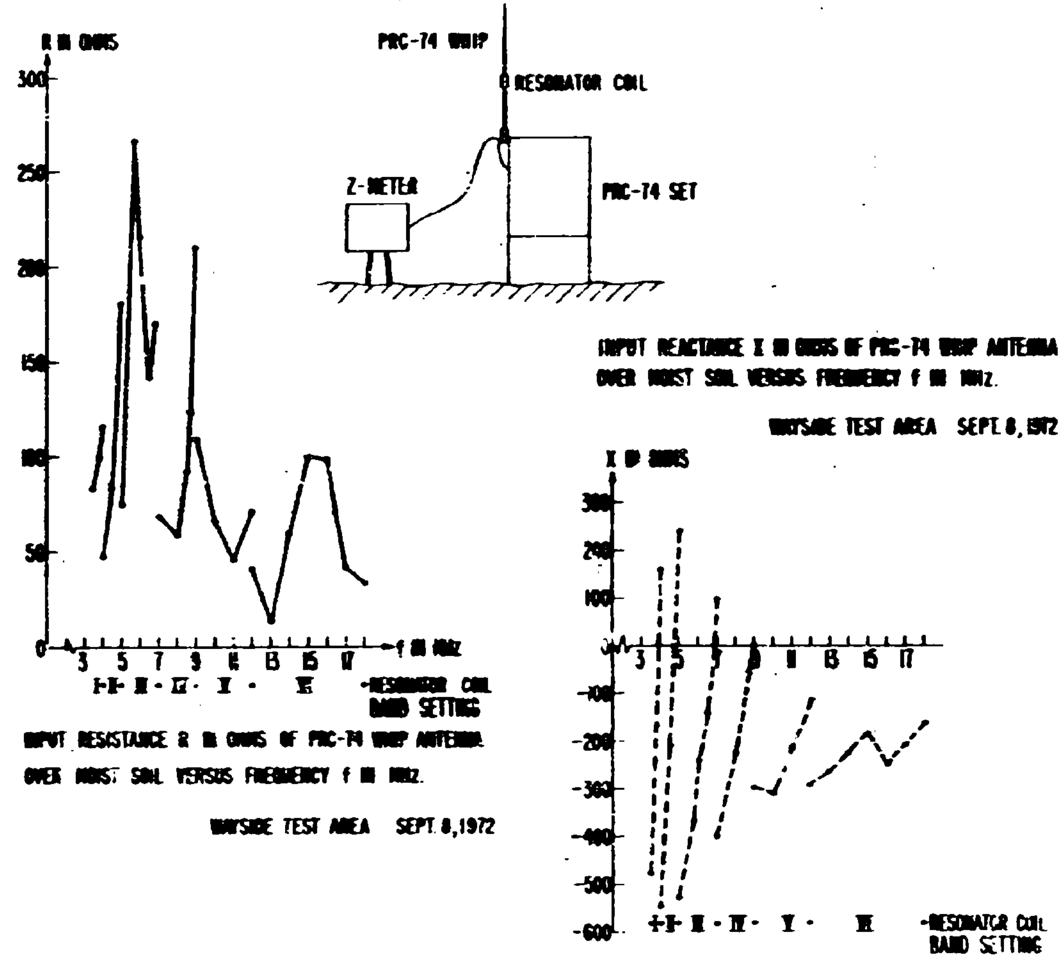


Fig. 16 PRC-74 Whip Input Resistance
and Reactance
Wayside Test Area Sept. 1972

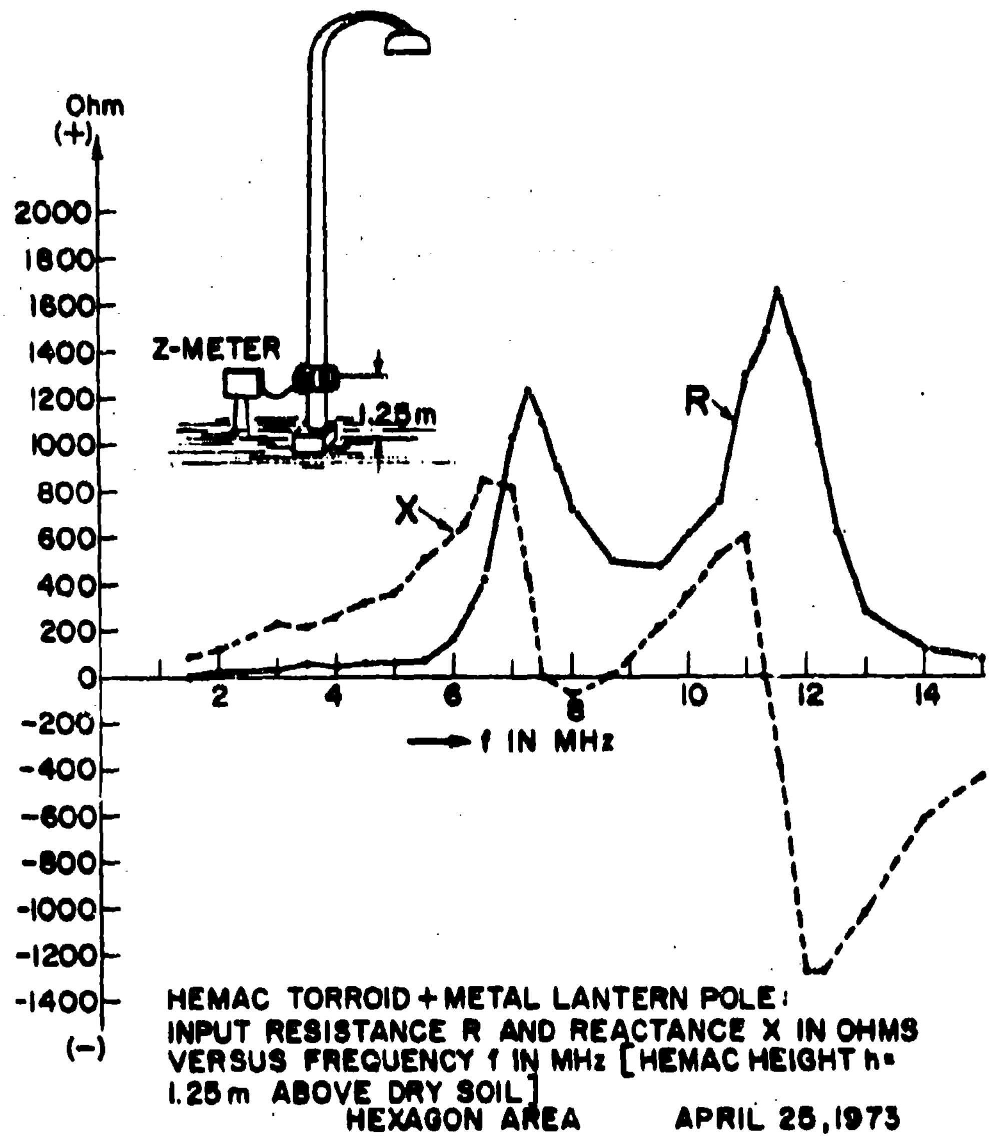


Fig. 17 HEMAC-Toroid Plus Metal Lantern
Pole Input Resistance and
Reactance
Hexagon Area April 1973

Fig. 18 PRC-74 Whip and HEMAC Coupled Tree Setup (10.803 MHz Transmission Hex to Evans Area)
Hexagon Area Feb. 1973

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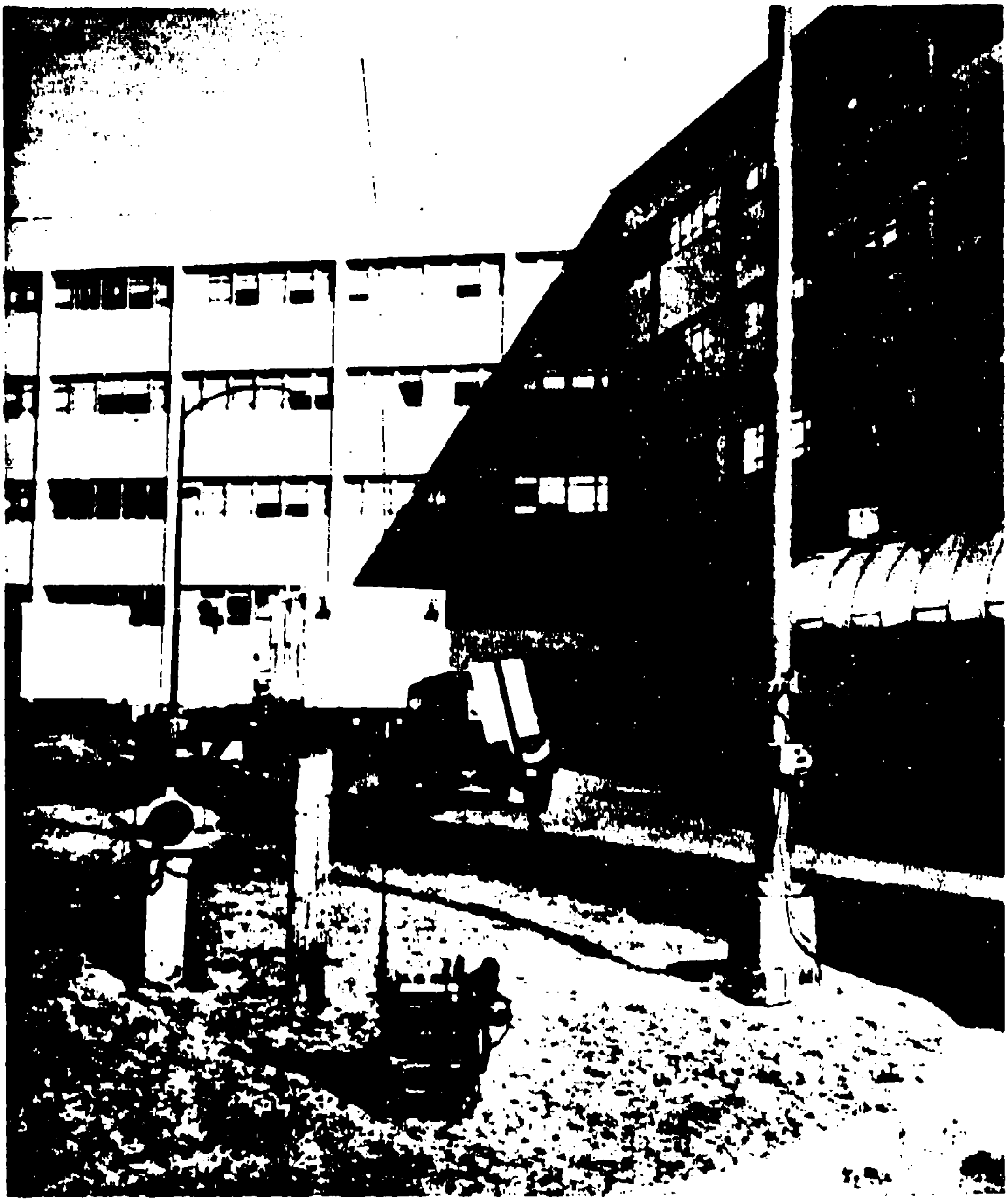

Fig. 19 PRC-74 Whip and HEMAC Coupled Lantern Pole Setup (10.803 MHz Transmission Hex to Evans Area) Hexagon Area Feb. 1973

Fig. 20 HEMAC Coupled Tree Setup (Close-up View) 10.803 MHz Transmission Hex to Evans Area Hexagon Area Feb. 1973

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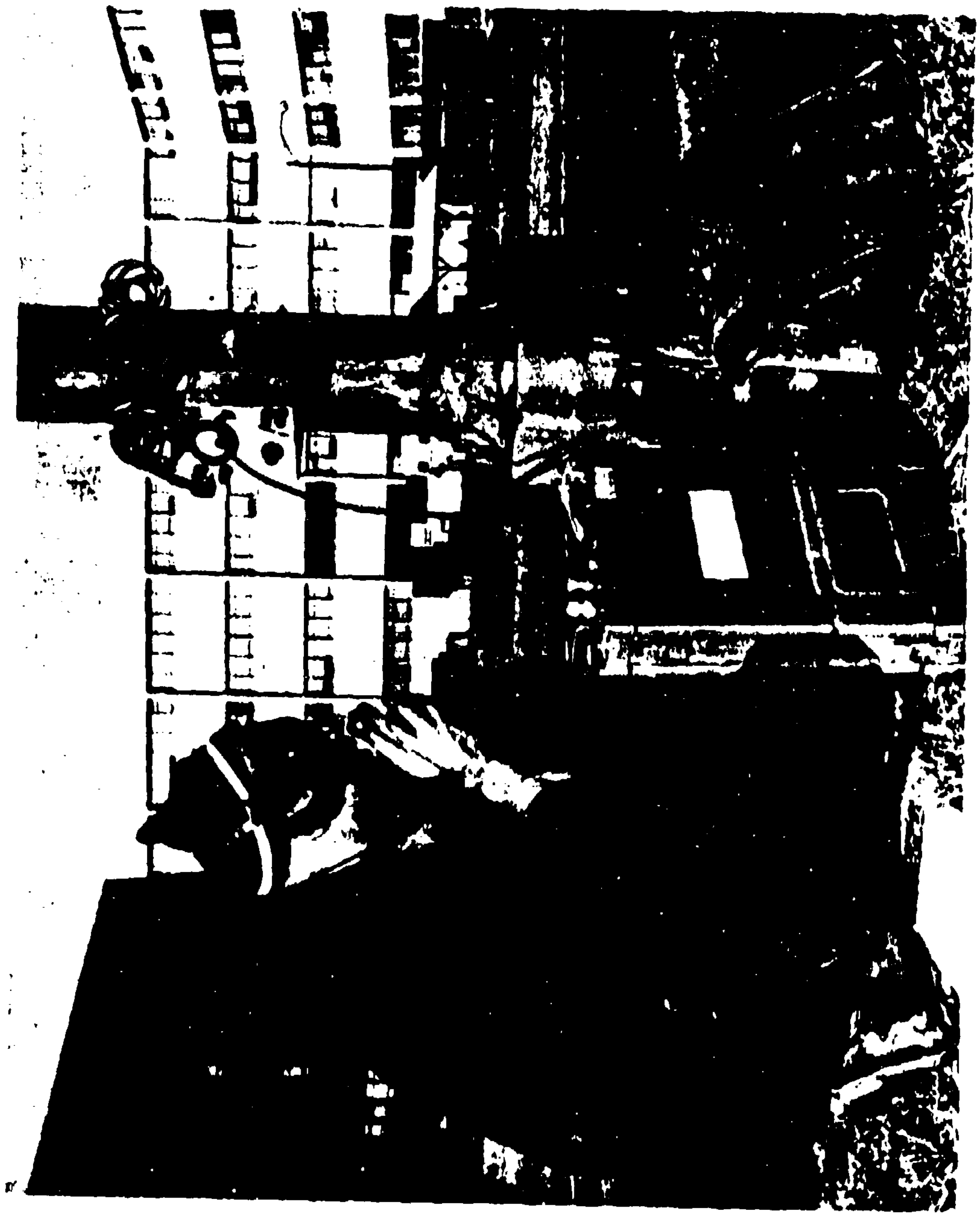

Fig. 21 HEMAC Coupled Lantern Pole Setup (8.050 MHz Transmission Hex to Evans Area)
Hexagon Area Nov. 1972

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Fig. 22 HEMAC Coupled Lantern Pole Setup (10.803 MHz Transmission Hex to Evans Area)
Hexagon Area Feb. 1973

Fig. 23 HEMAC Coupled Lantern Pole - Matchbox (Close-up View) Hexagon Area Feb. 1973

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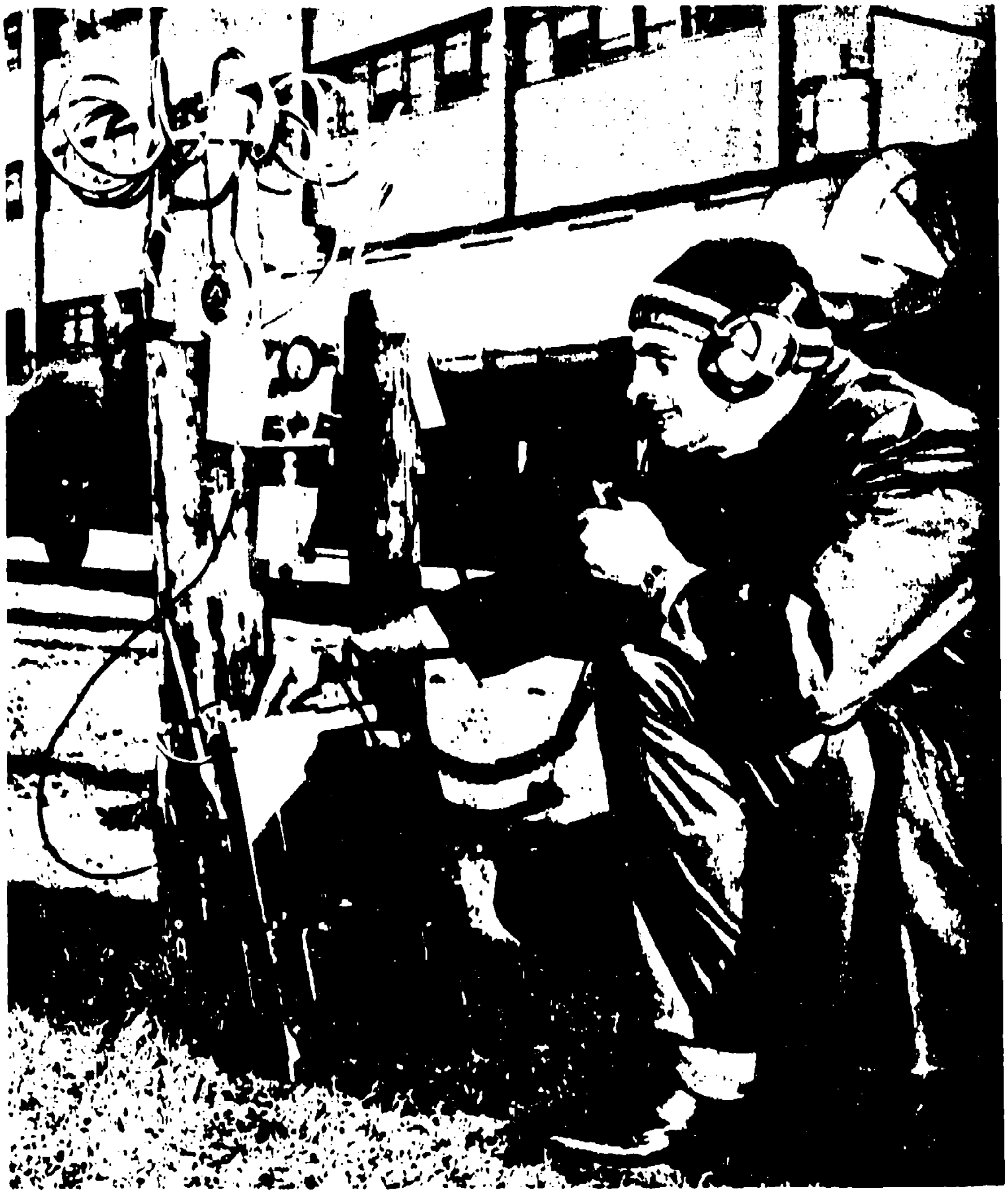

Fig. 24 HEMAC Coupled Short Wooden Pole Setup (10.803 MHz Transmission Hex to Evans Area)
Hexagon Area Feb. 1973

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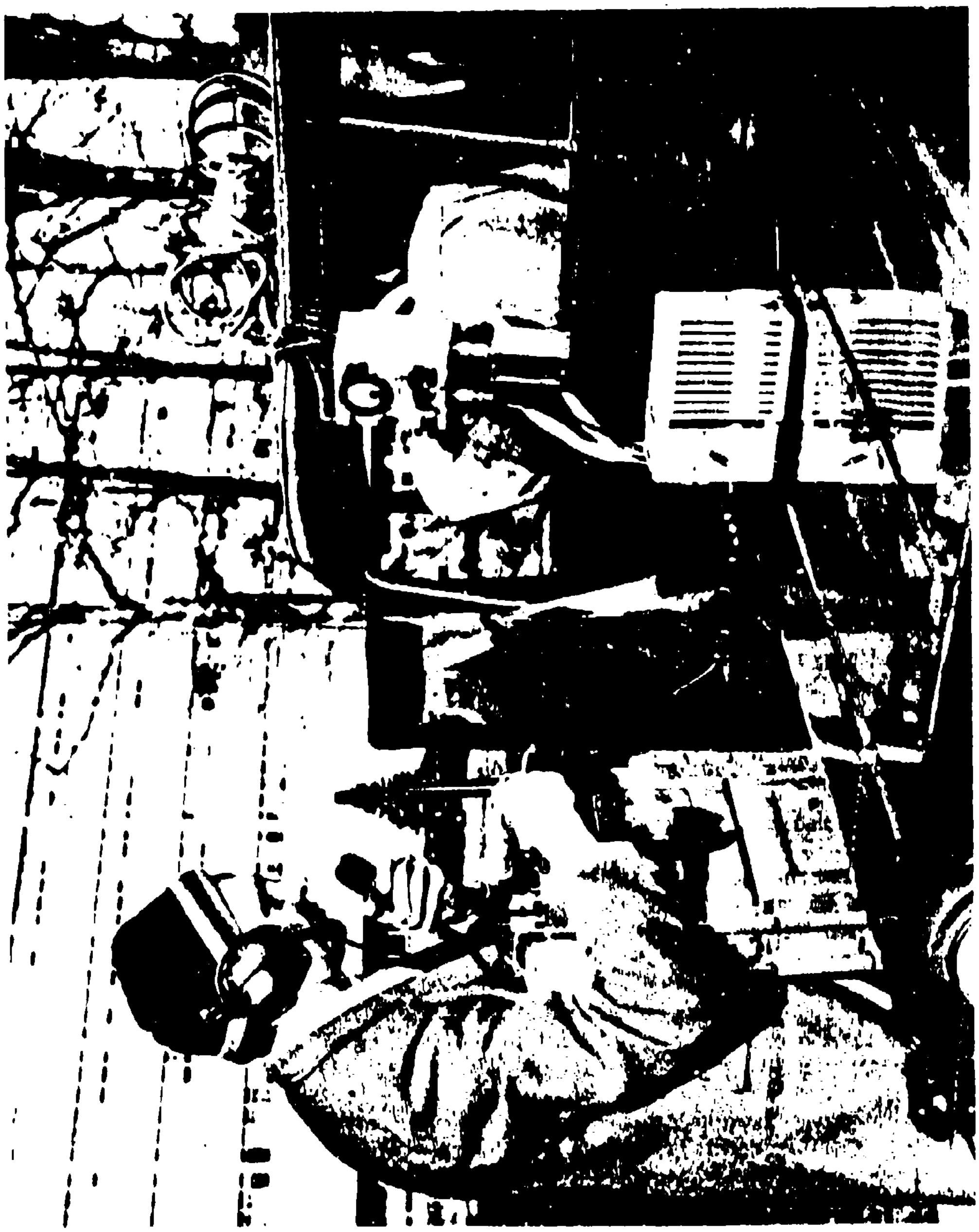

Fig. 25 HEMAC Coupled Jeep Setup
(10.803 MHz Transmission Hex
to Evans Area)
Hexagon Area Feb. 1973

radio transceiver setups on frequencies between 5.5 MHz and 11.0 MHz were received and measured at station AD2XL in the Camp Evans Area (Bldg. T-113) about seven miles south from the Hexagon-Camp Charles Wood Area. Pictures of this station are shown in Figures 26 and 27. One may note that the horizontal wire doublet antennas of the station are oriented for optimal reception of signals arriving from east and west rather than from north and south. In one case the emitted signals were also monitored and measured inside the Hexagon building, in Room 4D423, using the BK-2007 heterodyne volt meter and a short whip antenna. The resultant data are tabulated in Figures 28 to 30. A comparative inspection of these data leads to the following conclusions: The HEMAC coupled lantern poles outperformed all other radiators at all times and on all frequencies between 6 and 11 MHz. Radiation from the PRC-74 whip is from 2 dB to 12 dB lower than that from the lantern poles. The performance as antennas of the HEMAC coupled small tree and of the jeep are about equal to the performance of the PRC-74 whip antenna; the tree being slightly better than the whip in the majority of cases and particularly then when the noise and RFI levels at the receiver station were relatively high. Radiation from the HEMAC by itself, with the HEMAC placed on a wooden table and on the short wooden pole (Fig. 24) is from 10 dB to 18 dB lower than that from the lantern poles.

Similarly to the previously described attempt to use a twin HEMAC coupled tree to control ground and sky wave emission, a transmission test was carried out with a twin HEMAC coupled lantern pole as radiator. However, having learned from the past, no attempt was made to power the twin HEMAC coupled lantern pole from two phased transmitters. Instead as seen in Figure 31 a single PRC-74 set used as a XMTR feeding directly either the upper, or the lower HEMAC such that the lower and upper HEMAC act as parasitic elements, such as the reflective and directive elements of a Yagi antenna. Furthermore, both HEMACs were fed in parallel and tuned for maximal radiation. The results, (Table - Fig. 30) show that the latter case is the worst of all, so much so that the signal is 6 dB and 3 dB down relative to the first and second case.

Considering the evident superiority of the metal lantern poles as antennas relative to the approximately equal performance of the small tree and the PRC-74 whip antenna, one may wonder to what extent the results of these ground to ground transmission tests were influenced by differences in the ground and sky wave radiation emissions. In this connection it should be pointed out that both the overall radiation efficiency, as well as the ground and sky wave emission mechanisms, are greatly influenced by the ground and the grounding conditions of the respective radiators.

In order to obtain an idea on the spatial distribution of radiation for the design of subsequent tests and measurements by airplanes an "aerial tramway" was set up between the Hexagon roof and a lantern pole at the movie theater east of the Hexagon. The nylon string of the aerial tramway was suspended in such a way that one of the shade trees and a lantern pole were located about half way beneath the aerial tramway. The gondola of the tramway was moved upward towards the Hexagon roof and downward towards the movie theater by nylon strings running through a pulley at the Hexagon roof.

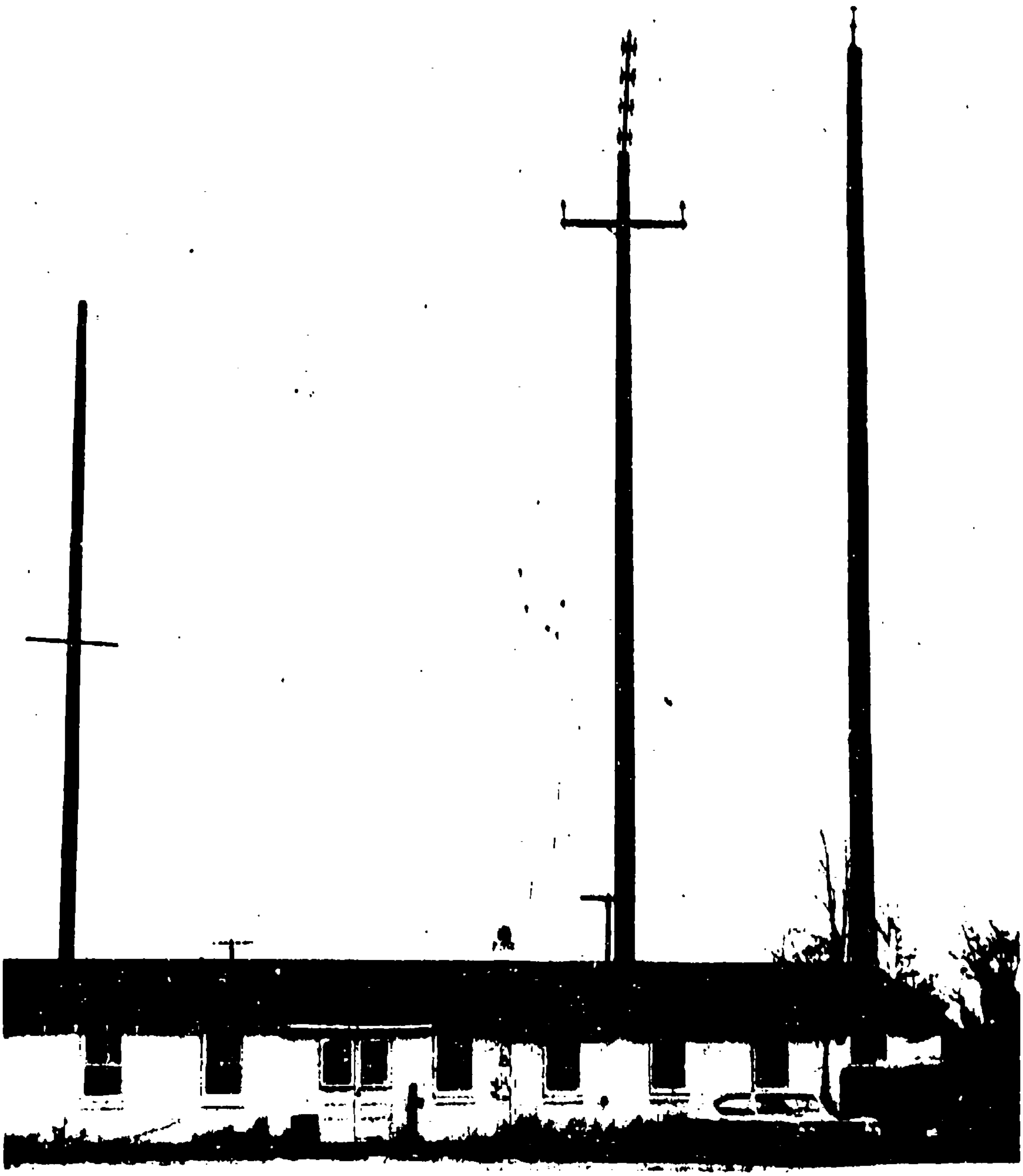

Fig. 26 Station AD2XL
Evans Area - (Antennas)

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Fig. 27 Station AD2XL
Evans Area - (Receiver)

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VOICE AND CW RADIO TRANSMISSION TEST DATA FOR THE STANDARD WHIP ANTENNA AS-1887/PRC 74, FOR HEMAC COUPLED METAL LANTERN POLES AND A SHORT WOODEN POLE LOCATED IN THE HEXAGON YARD AND SERVING AS XMTR ANTENNAS FOR A PRC-74 RADIO SET. (old set: serial No 8; available Power Output ≈ 7 Watt)

DATE OF TEST	EMITTED SIGNAL FREQUENCY	XMTR ANTENNA		SIGNAL AND NOISE LEVELS RECEIVED AT CAMP EVANS STATION AD2XL (Bldg. [illegible]) VIA WIRE ANTENNA AND R390A RECEIVER	
17 NOV. 72 afternoon	2.050 MHz	HEMAC (b1)	coupled LANTERN POLE	Voice Quality / Signal Strength = clear / strong = 5/5	
			by itself on WOODEN TABLE	Voice, Tone Signals are not received	
9 JAN. 73 afternoon	5.581 MHz	HEMAC (b2) coupled LANTERN POLE		S+N = 22 dB	N = 8 dB
10 JAN. 73 afternoon	6.000 MHz	HEMAC (I) coupled LANTERN POLE		S+N = 18 to 20 dB	N ≈ 10 dB
	6.500 MHz			S+N = 25 to 30 dB	N = 10 to 15 dB
30 JAN. 73 afternoon	11.000 MHz	Standard WHIP		S+N = 22 dB	N = 10 dB
		HEMAC (I)	coupled LANTERN POLE	S+N = 28 dB	N = 10 dB
			coupled SHORT WOODEN POLE (protecting Fire Hydrant)	S+N ≈ N = 10 dB	
14 FEB. 73 before noon	10.803 MHz	Standard WHIP		S+N = 28 dB	N = 18 dB
		HEMAC (I)	coupled LANTERN POLE	S+N = 30 dB	N = 18 dB
			coupled SHORT WOODEN POLE (protecting Fire Hydrant)	S+N = 20 dB	N = 18 dB

REMARKS : HEMAC(b1) and (b2) are flexible Toroids with 6 cm coildiameter and respectively 16 and 25 turns fed by Matching Circuit No. 2. [HEMACS (a1) and (a2) were used previously with Body Coupled XMTR's]

HEMAC(I) is a Tygon Tubing insulated 1/4" Copper Tube Toroid with 5 1/2" Coil Diameter and 10 Turns fed by Matching Circuit No. 3

Fig. 28 Voice and CW Radio Transmission
Test Data Hex to Evans Area
(Whip, HEMAC-Poles)
Nov. 1972 to Feb. 1973

VOICE AND CW RADIO TRANSMISSION TEST DATA FOR THE STANDARD WHIP ANTENNAS AS-1887A/PRC 74, FOR A HEMAC COUPLED METAL LANTERN POLE, A SMALL TREE AND A CANVAS COVERED JEEP LOCATED IN THE HEXAGON AREA IN THE VICINITY OF BLDG. 2704 AND SERVING AS XMTR ANTENNAS FOR A PRC-74 RADIO SET.

DATE OF TEST	TRANSMITTER AND EMITTED SIGNAL CHARACTERISTICS					SIGNAL AND NOISE LEVELS RECEIVED AT:			
						CAMP EVANS STATION AD2XL (BLDG. T113) VIA WIRE ANTENNA AND R390A RADIO RECEIVER		HEXAGON ROOM 4D232 VIA WHIP ANTENNA AND "BK" HETERODYNE VOLT-METER TYPE 2007	
8 FEB 73	PRC74	POWER (WATT)	FREQUENCY (MHz)	XMTR ANTENNA					
before noon	OLD SET SERIAL No. 8	7	10.800	standard WHIP		$S \leq N = 10\,dB$		$S+N = 8\,mV$	$N \approx 0.1\,mV$
				HEMAC[1] coupled	LANTERN POLE	$S+N = 18\,dB$	$N = 10\,dB$	$S+N = 33\,mV$	$N \approx 0.1\,mV$
					SMALL TREE	$S \leq N = 10\,dB$		$S+N = 9\,mV$	$N \approx 0.1\,mV$
after noon	NEW SET SERIAL No. 131A	9	8.003	standard WHIP		$S+N = 8\,dB$	$N = 5\,dB$	$S+N = 15\,mV$	$N \approx 1.0\,mV$
				HEMAC[1] coupled	LANTERN POLE	$S+N = 10\,dB$	$N = 5\,dB$	$S+N = 22\,mV$	$N \approx 1.0\,mV$
					SMALL TREE	S = audible not measurable	$N = 5\,dB$	$S+N = 13\,mV$	$N \approx 1.0\,mV$
					JEEP	S = audible not measurable	$N = 5\,dB$	$S+N = 9\,mV$	$N \approx 1.0\,mV$

REMARKS: HEMAC[1] is a Tygon Tubing insulated ¼" Copper tube Toroid with 5⅞" Coil Diameter and K. turns fed by Matching Circuit No. 3

Fig. 29 Voice and CW Radio Transmission Test Data (Whip, HEMAC, Pole, Tree) Feb. 1973

VOICE AND CW RADIO TRANSMISSION TEST DATA FOR THE STANDARD WHIP ANTENNA AS-1887/PRC-74, FOR A HEMAC COUPLED METAL LANTERN POLE, SMALL TREE AND A CANVAS COVERED JEEP LOCATED IN THE HEXAGON AREA, IN THE VICINITY OF BLDG. 2704, AND SERVING AS XMTR ANTENNAS FOR A PRC-74 RADIO SET. (old set: Serial No. 8; available Power Output ≈ 7 Watt)

DATE OF TEST 14 Feb. 73	EMITTED SIGNAL FREQUENCY (MHz)	XMTR ANTENNA		SIGNAL AND NOISE LEVELS RECEIVED AT CAMP EVANS STATION AD2XL (Bldg. T83) VIA WIRE ANTENNA AND R390A RADIO RECEIVER	
before noon	10.803	standard WHIP		S ≤ N = 18 dB	
		HEMAC(1) coupled	LANTERN POLE	S+N = 25 dB	N = 18 dB
			SMALL TREE	S = audible, not measurable	N = 18 dB
			JEEP	S ≤ N = 18 dB	
after noon	10.807	standard WHIP		S+N = 18 dB	N = 5 dB
		HEMAC(2) coupled LANTERN POLE		S+N = 20 dB	N = 5 dB
	8.034	TWIN HEMAC(2) ARRAY coupled LANTERN POLE	top Hemac on, bottom Hemac off	S+N = 15 dB	N = 3 dB
			top Hemac on, direct, bottom Hemac on, parasitic	S+N = 18 dB	N = 3 dB
			top and bottom Hemac's on, direct in series	S+N = 12 dB	N = 3 dB

REMARKS: HEMAC(1) is a Tygon Tubing insulated 3/8" Copper Tube Toroid with 5 1/2" Coil diameter and 10 turns fed by Matching Circuit No. 3.
HEMAC(2) is of similar construction and has 4" Coil diameter and 11 Turns fed by Matching Circuit No. 3

Fig. 30 Voice and CW Radio Transmission Test Data Hex to Evans Area (Whip, HEMAC, Pole, Tree and Twin HEMAC-Pole) Feb. 1973

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Fig. 31 Twin HEMAC Coupled Lantern Pole Setup (8.034 MHz Transmission; Hex to Evans Area)
Hexagon Area Feb. 1973

Pictures of the aerial tramway - gondola experimental setup are shown in Figures 32 to 36. The gondola carried a small 1 watt RF transistor XMTR operating on a frequency of 8.25 MHz. The experiments were made with the small HEMAC coil that can be seen in the pictures (Figs. 32 to 34) and with a 1 meter long vertical wire as XMTR antennas. The experimental setups and test objects such as lantern pole, tree, PRC-74 whip and the HEMAC by itself are described by the illustrations above the recordings in Figures 35 to 45. These recordings give the output voltages from the test objects as functions of the position and movement of the XMTR gondola above. The recordings were made with a TR-722 recorder connected to the recorder output of the BK Heterodyne Voltmeter. Pulling the gondola XMTR upward was more difficult and slower than pulling it downward with the ends of the strings on the parking lot between the Hexagon and the movie theater and with the pulley located on the Hexagon roof. The upward and downward recordings are distorted since the recording speed is not synchronised with upward and downward speeds of the transmitter gondola. Furthermore, the battery of the gondola - XMTR was running down during the tests; consequently, the peak voltage outputs from the different test objects reflects to some extent this drainage of the XMTR battery. It is also necessary to point out that the recorded output voltages are indicative of essentially the interaction of the test object with the gondola XMTR's near fields rather than with its' radiation field. Nevertheless, insofar as different near fields correspond to different radiation fields, the recordings in Figures 35, 36 and 37,38 for respectively the lantern pole and the tree prove that the primary objectives of the experiments were achieved. The lantern pole and tree, coupled by identical HEMACs and immersed into practically identical RF fields from the HEMAC antenna equipped gondola XMTR, deliver drastically different recordings. The lantern pole output is double-lobed and has a deep null when the XMTR gondola is directly over it so that the resultant pattern is double-lobed. The tree output is broad with a flat maximum of the pattern when the gondola XMTR is directly above the tree. The fine structure of the tree output is seen in the recording in Figure 39. The wiggled fine structure is caused largely by the jerky movement and wind induced swinging of the gondola XMTR. The previously mentioned relative distortion of upward and downward recordings is clearly seen in Figure 40 for the tree case. Similarly, Fig. 41 shows the upward and downward records for the PRC-74 whip. Considering that the whip and metal light pole are "vertical electrical rod antennas" the completely different shapes of the PRC-74 whip and of the lantern pole recordings (Fig. 41 and Figs. 35, 36) are surprising. The null of the lantern pole record with the gondola HEMAC XMTR directly above the pole agrees with expectations founded on idealised grounding conditions. The flat maxima in the whip case under the same conditions could be reconciled with the existence of entirely different grounding conditions for the PRC-74 set in conjunction with the influence of the center coil resonator on the induced whip current distribution. Similar recordings obtained with the one meter long vertical wire instead of the HEMAC coil as gondola XMTR antenna are shown in Figures 36 to 39. In spite of the greater susceptibility of the vertical wire XMTR to wind and jerky movement induced deviations from vertical orientation and corresponding perturbations of the polarization of the emitted fields, one recognizes particularly in the lantern pole recordings the deep fadings of the output voltage when the XMTR is above the pole.

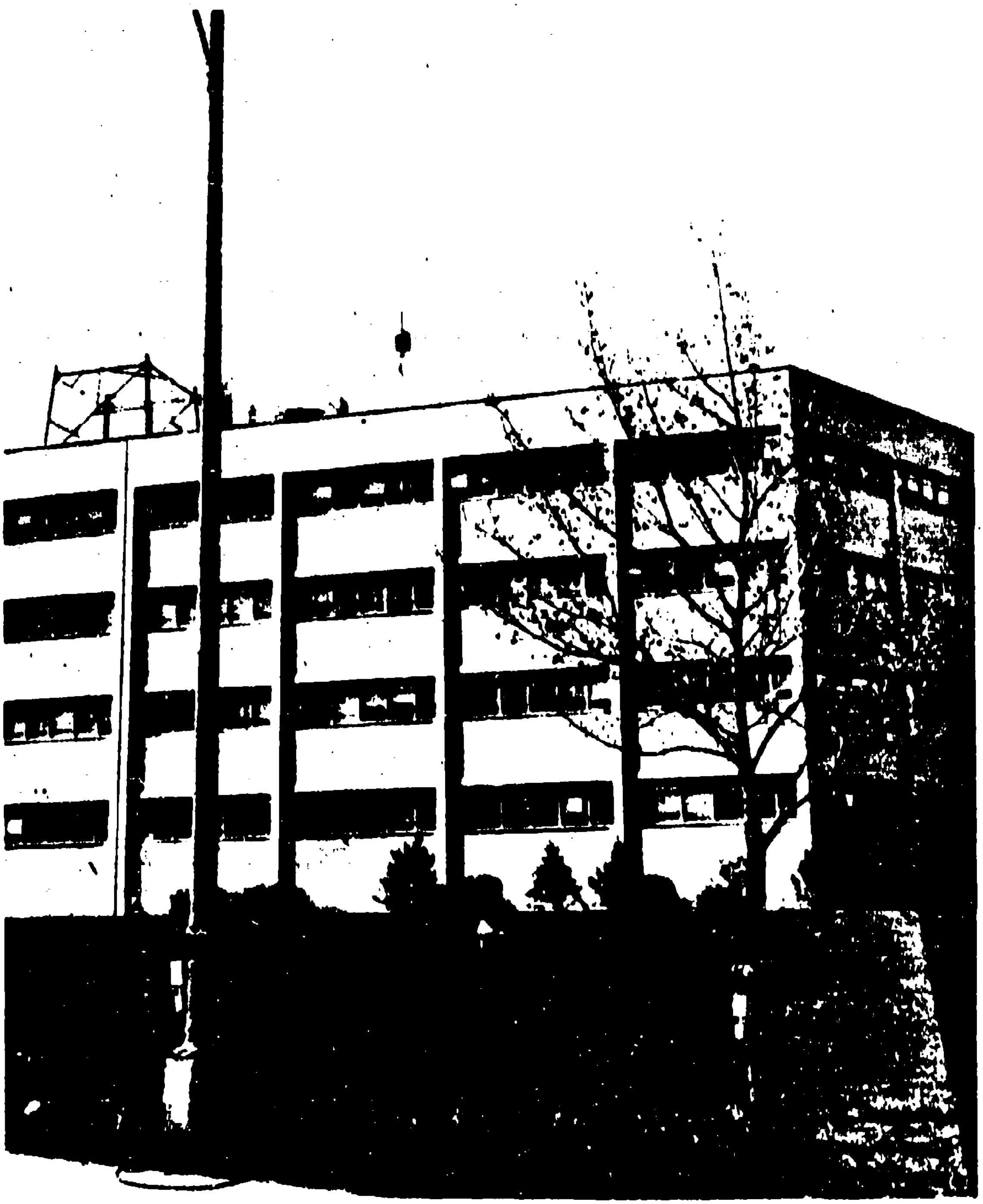

Fig. 32 Aerial Tramway Gondola 8.25 MHz XMTR above Tree and Lantern Pole Receiver Setup Hexagon Area April 1973

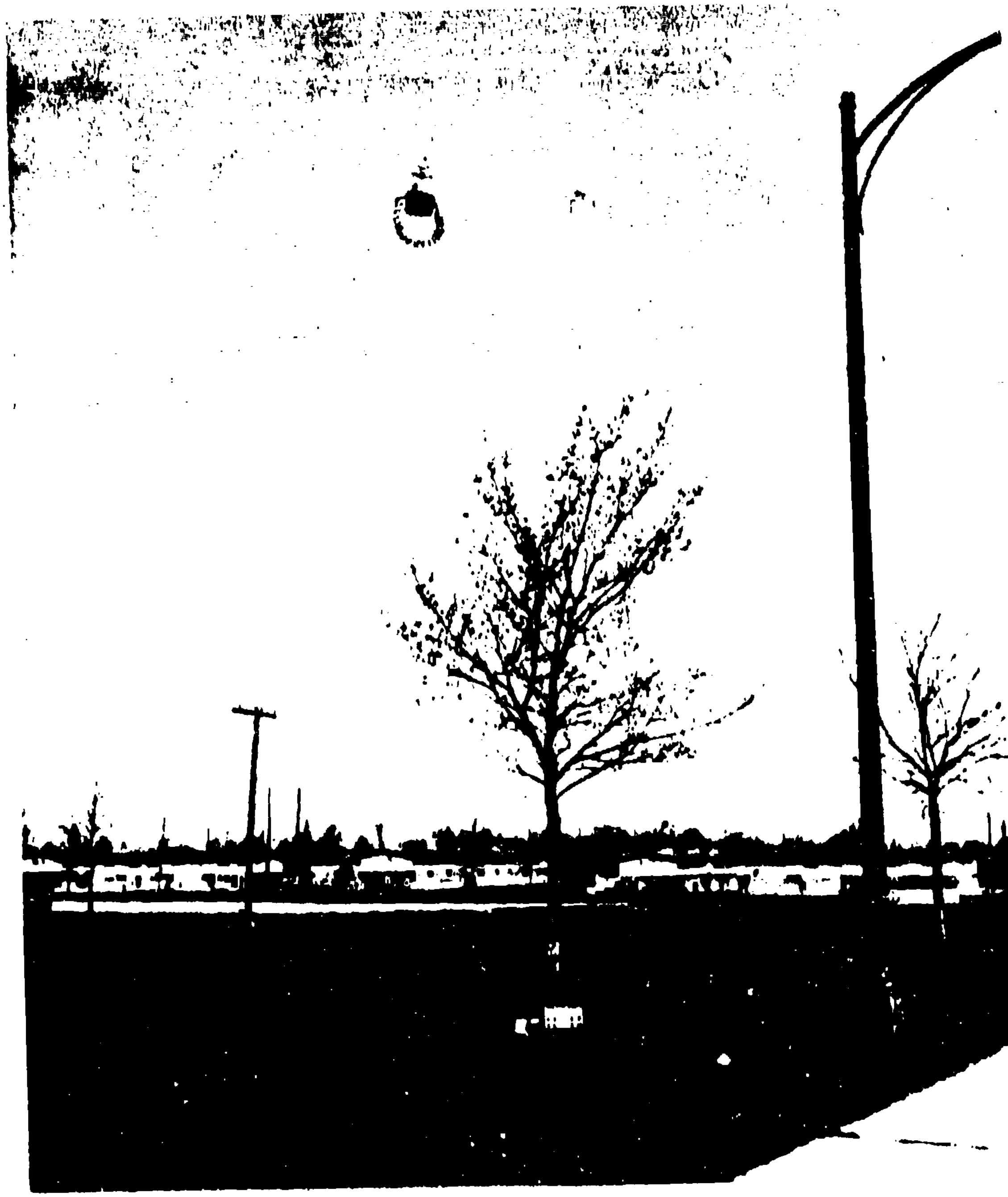

Fig. 33 Aerial Tramway Gondola 8.25 MHz XMTR Approaching Tree Top
Hexagon Area April 1973

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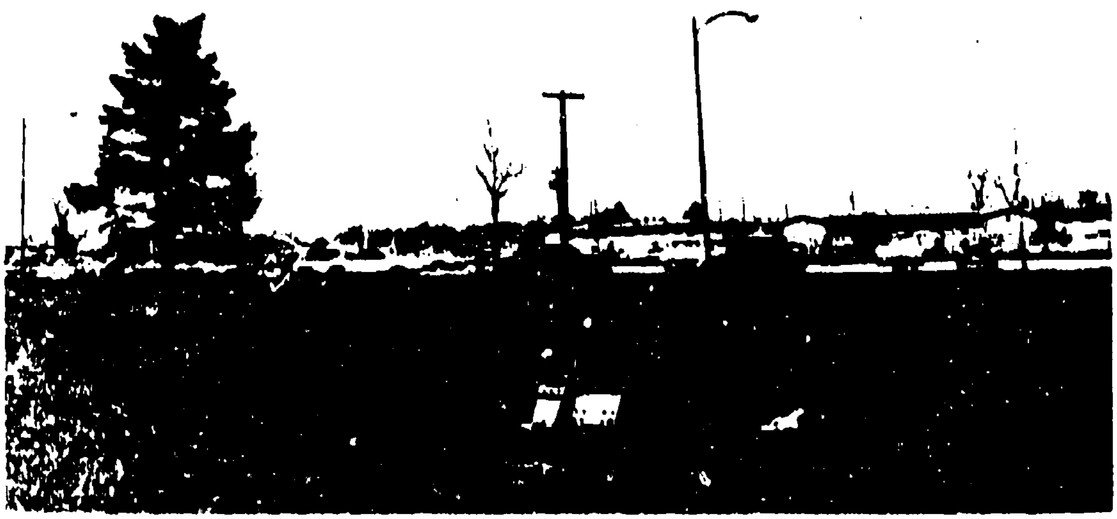

Fig. 34 Aerial Tramway Gondola 8.25 MHz
XMTR above PRC-74 Whip Receiver
Hexagon Area April 1973

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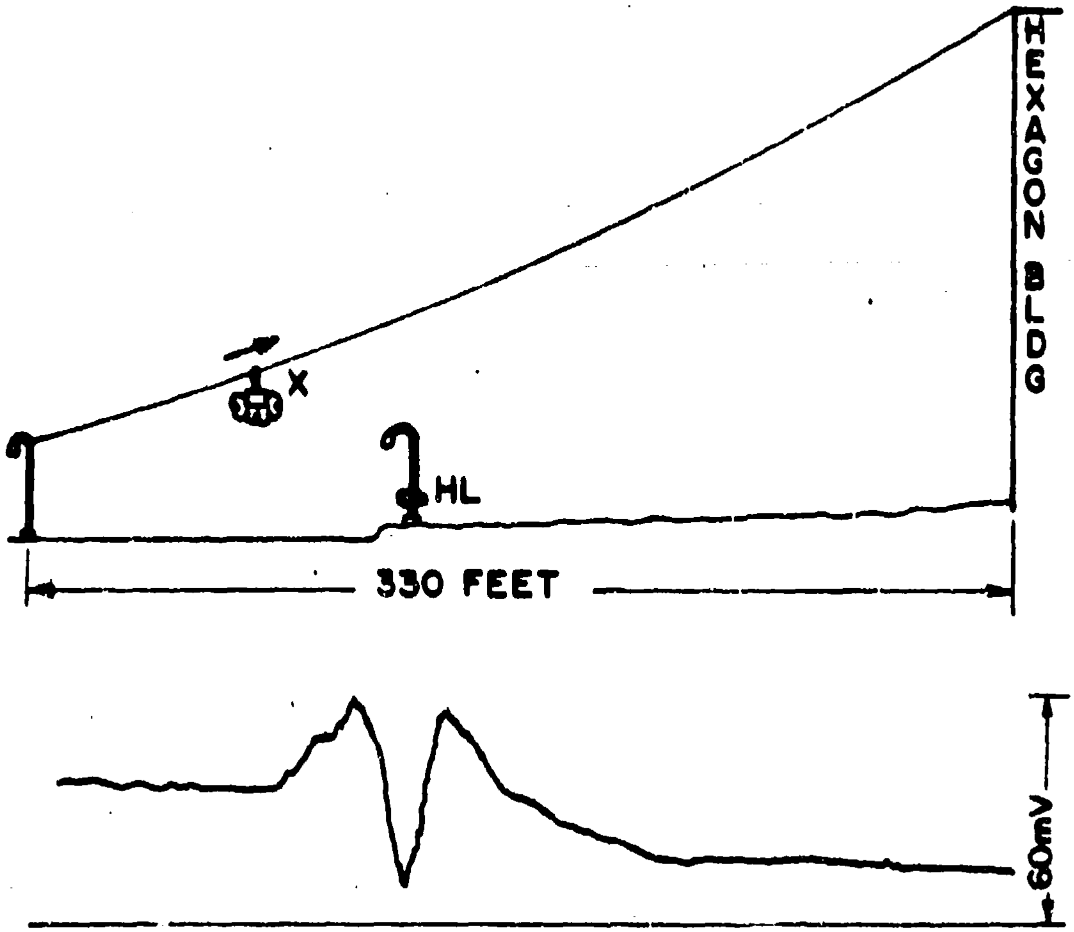
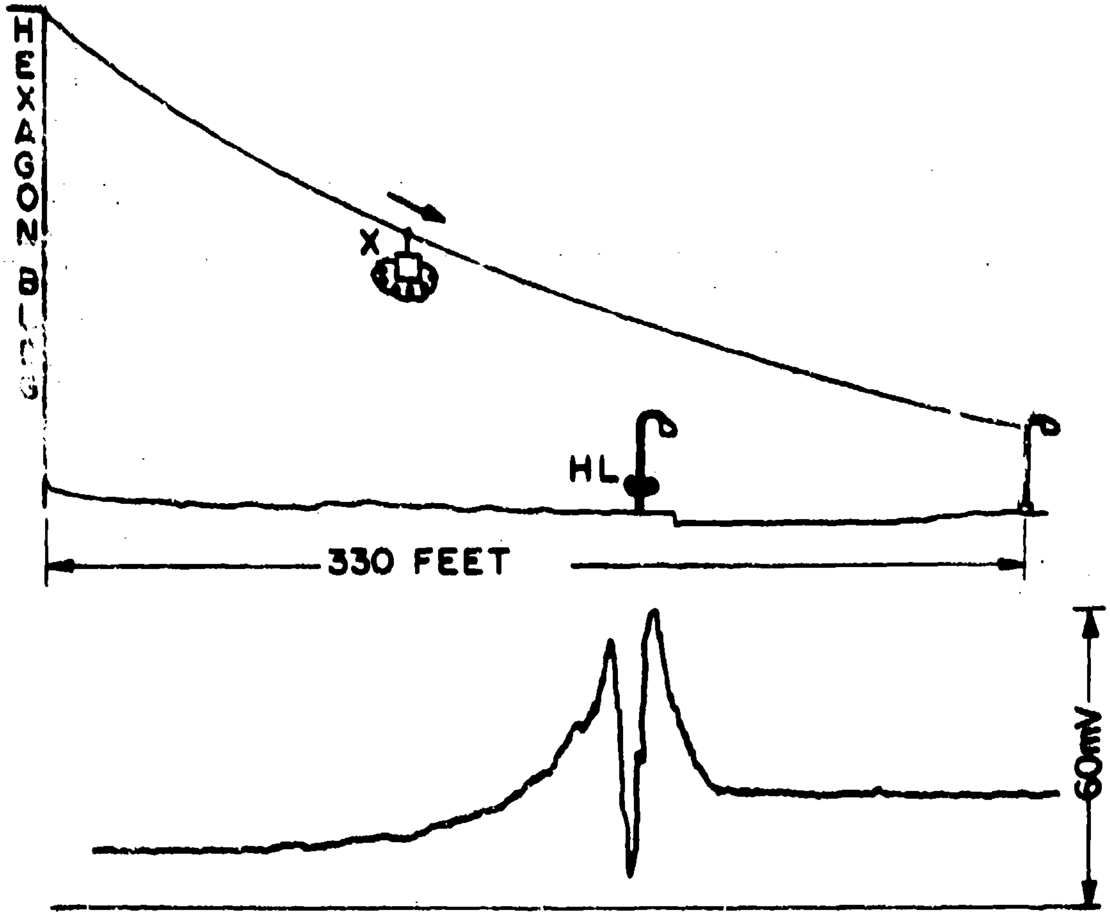


RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED LANTERN POLE (HL) VERSUS UPWARD MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR(X) APRIL 9,1973

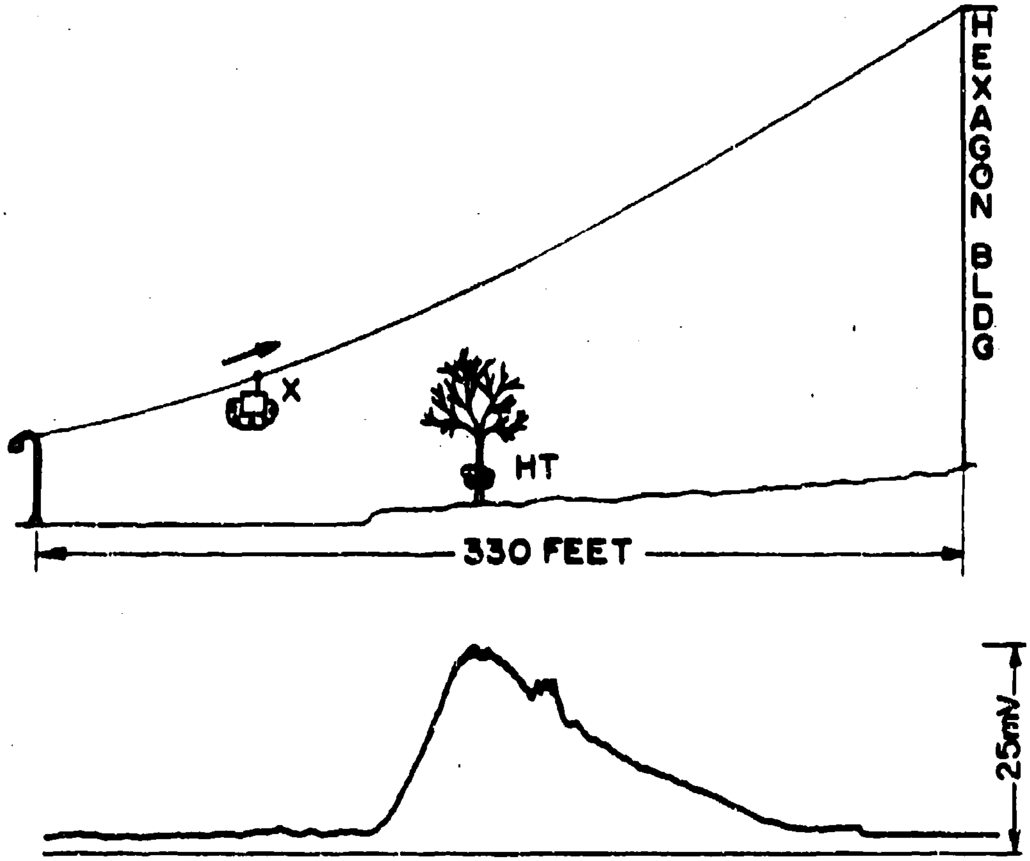
FIG. 35



RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED LANTERN POLE (HL) VERSUS DOWN WARD MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X)

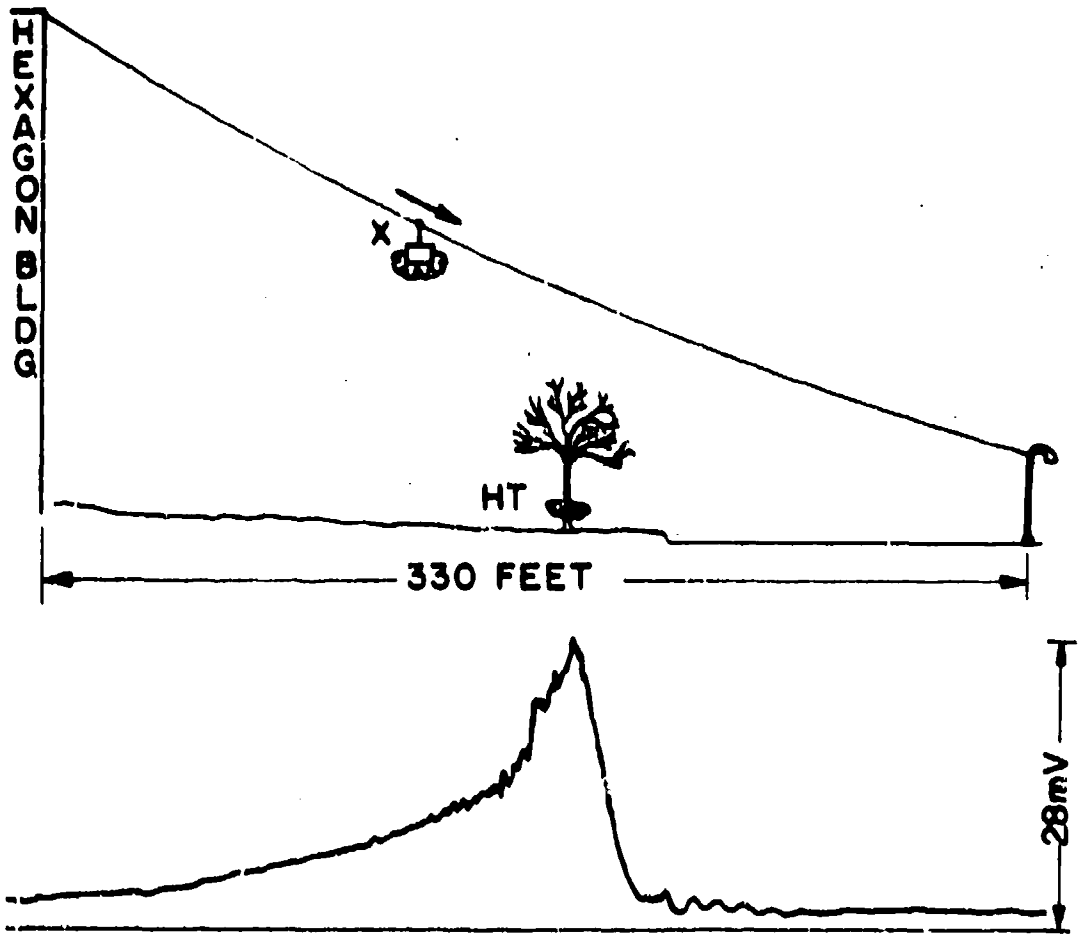
APRIL 9, 1973

FIG. 36



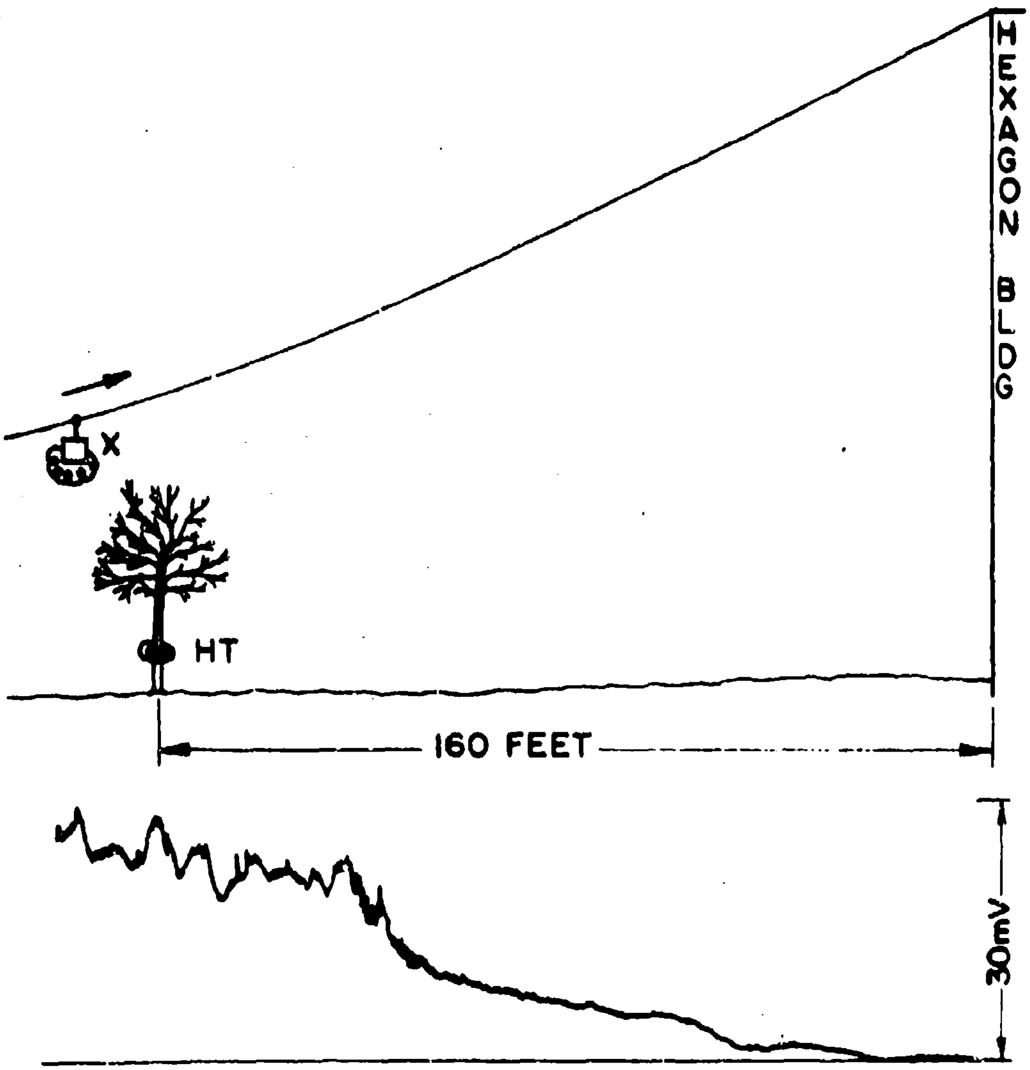
RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED TREE (HT) VERSUS UPWARD MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X) APRIL 9, 1973

FIG. 37



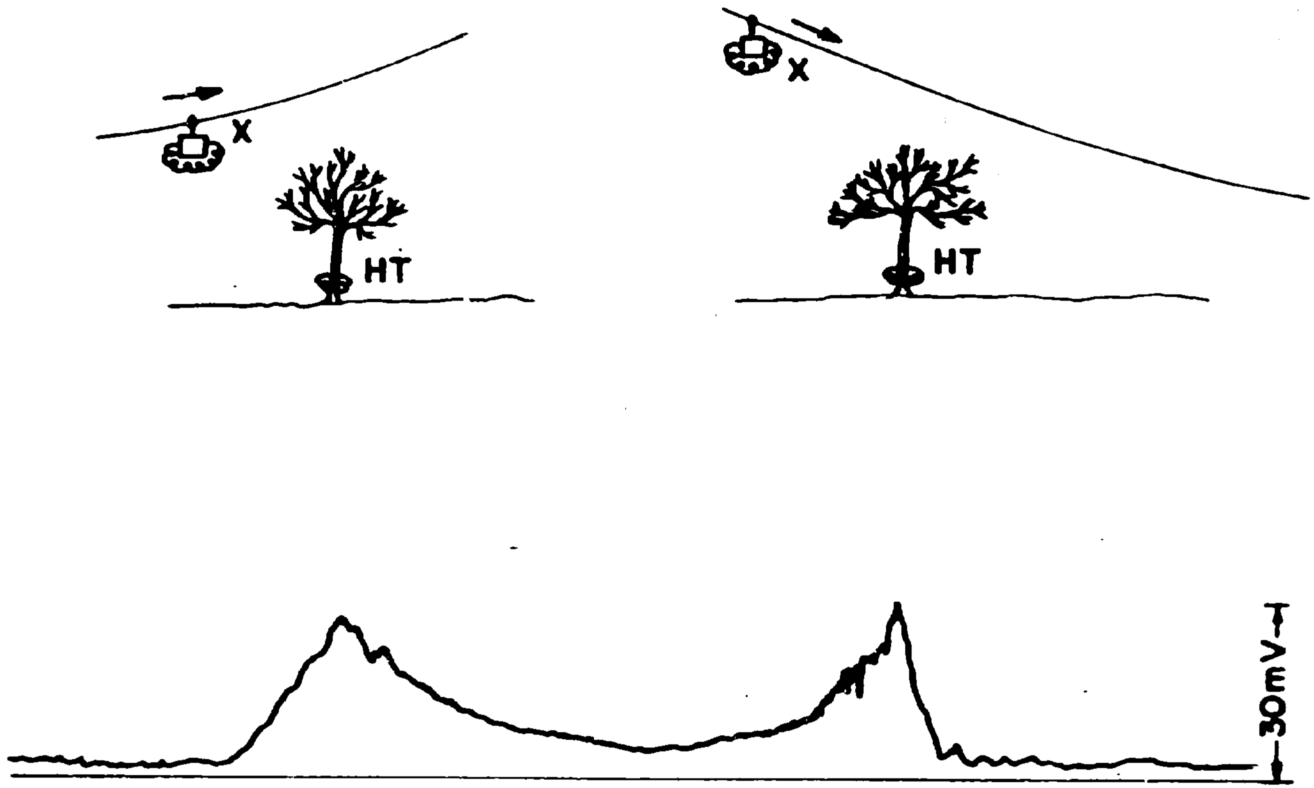
RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED TREE (HT) VERSUS DOWNWARD MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X)
APRIL 9, 1973

FIG. 38



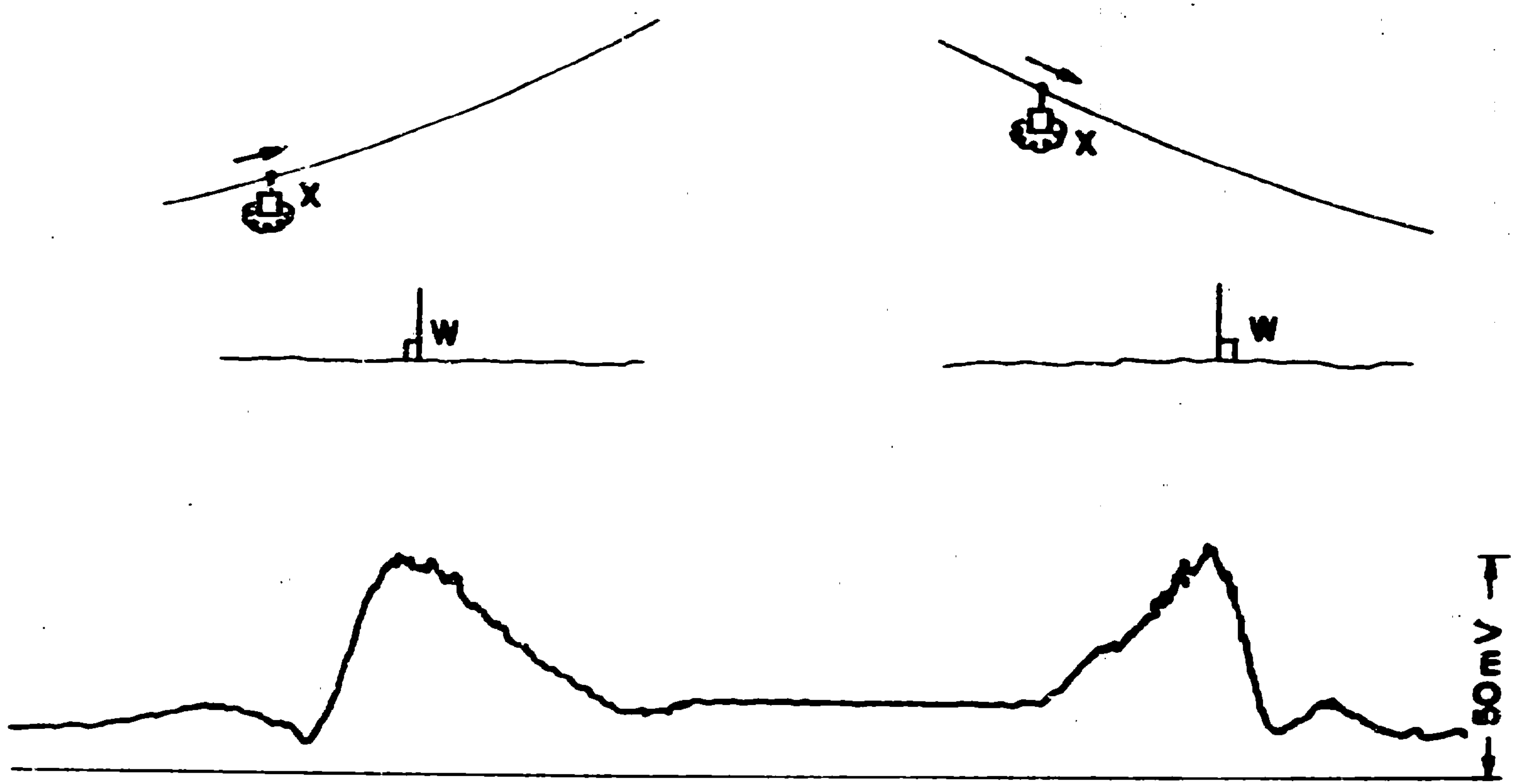
RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED TREE (HT) VERSUS MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X) UPWARD FROM ABOVE TREE TO ROOF OF HEXAGON. APRIL 9, 1973

FIG. 39



RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC COUPLED TREE (HT) VERSUS UPWARD (LEFT PART) AND DOWN WARD (RIGHT PART) MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X) APRIL 9, 1973

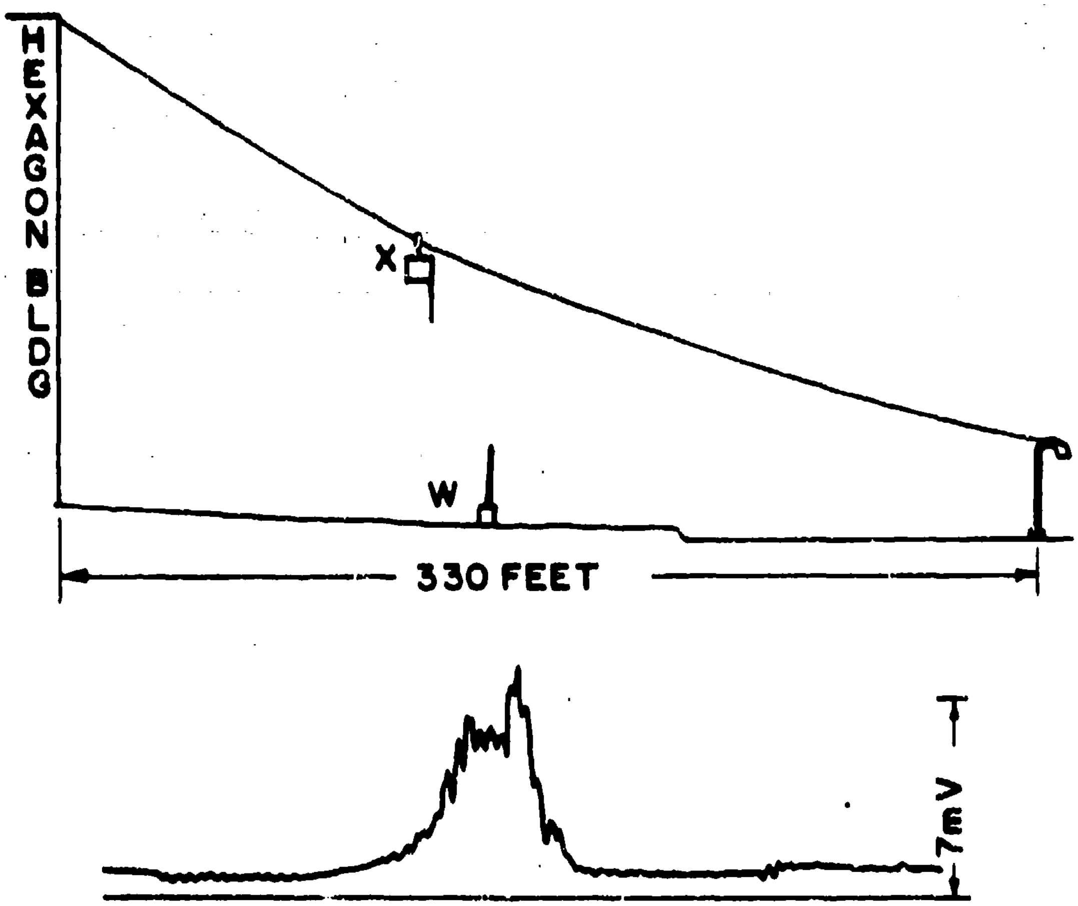
FIG. 40



RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM A PRC-74 - WHIP (W) VERSUS UPWARD (LEFT PART) AND DOWN WARD (RIGHT PART) MOVEMENT OF AERIAL TRAMWAY GONDOLA HEMAC XMTR (X)

APRIL 9, 1973

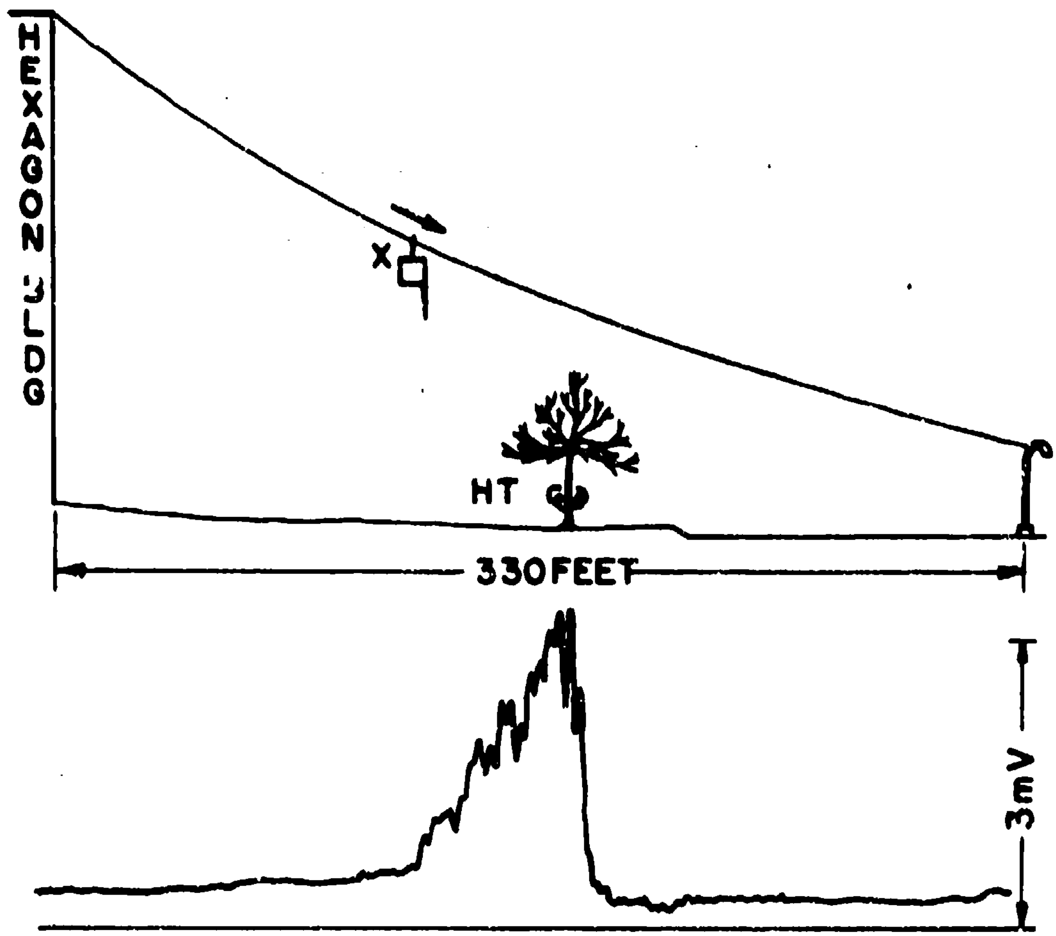
FIG. 41



RECORDING OF 8.25 MHz OUTPUT VOLTAGE FROM A PRC-74-WHIP (W) VERSUS DOWN WARD MOVEMENT OF AERIAL TRAMWAY GONDOLA WHIP XMTR (X)

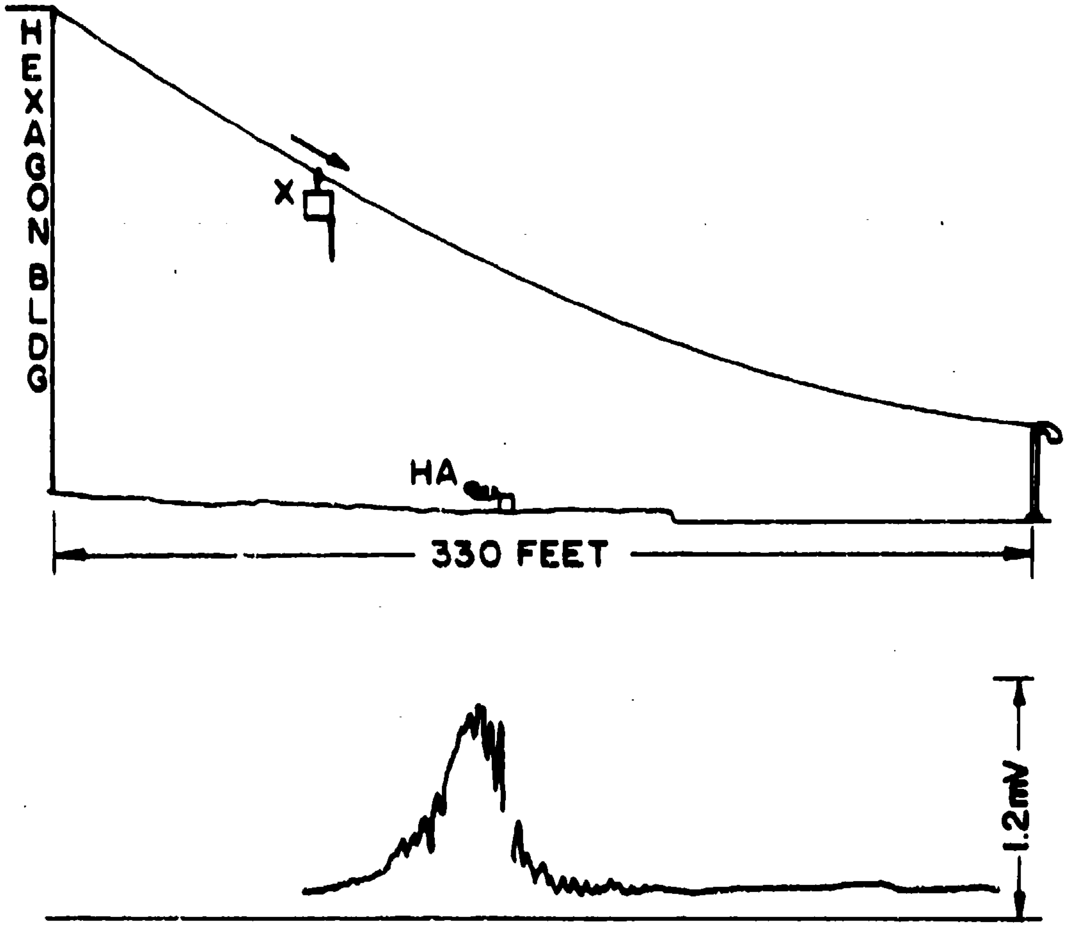
APRIL 16, 1973

Fig. 42



RECORDING OF 8.25 MHz OUTPUT VOLTAGE
AMPLITUDE FROM HEMAC COUPLED TREE(HT)
VERSUS DOWNWARD MOVEMENT OF AERIAL
TRAMWAY GONDOLA WHIP XMTR(X)
APRIL 16,1973

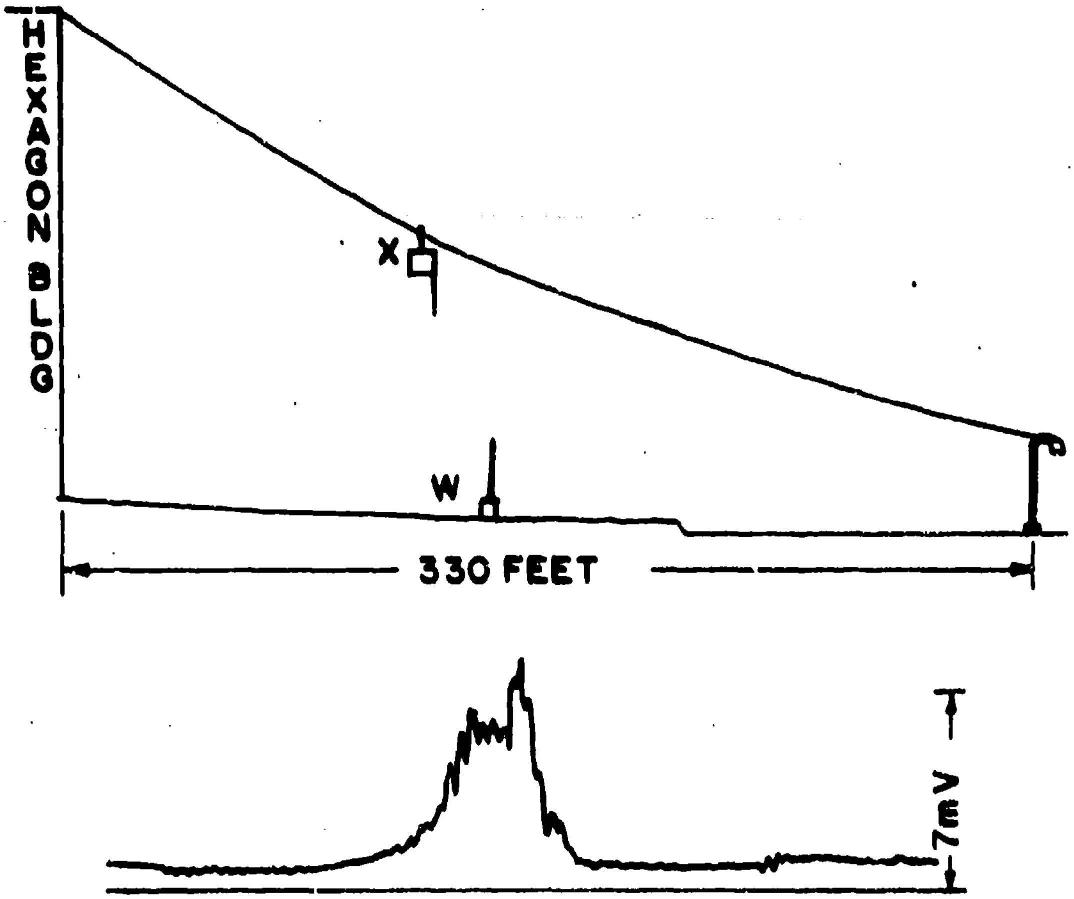
Fig. 43



RECORDING OF 8.25 MHz OUTPUT VOLTAGE AMPLITUDE FROM HEMAC IN AIR (HA) 18 INCHES ABOVE GROUND VERSUS DOWNWARD MOVE OF AERIAL TRAMWAY GONDOLA WHIP XMTR (X)

APRIL 16, 1973

Fig. 44



RECORDING OF 8.25 MHz OUTPUT VOLTAGE FROM A PRC-74-WHIP (W) VERSUS DOWN WARD MOVEMENT OF AERIAL TRAMWAY GONDOLA WHIP XMTR (X)

APRIL 16, 1973

Fig. 45

Hence, there is no doubt that radiation patterns from trees and from lantern poles must be different, particularly with respect to ground and sky wave radiation. Resultant implications for ground to air communications will be investigated in future tests using an airplane for this purpose. The fact that the metal lantern poles are plants of urban jungles and were put to work as efficient radio antennas leads deeper into the urban jungle and into the following technical area of application.

2. The Utilization of Buildings, Water and Power Lines as RF Antennas and Transmission Media.

(1) HF Signal Emanation and Reception by Building Structures.

In the introduction it was pointed out that the RF communications in urban jungles involves principally RF induction, conduction, and radiation in conjunction with diverse structures. Considering the structural and material similarities between conventional whip type antennas and metal lantern poles, the previously described utilization of lantern poles as antennas seems obvious. However, the use of buildings and of specific parts of buildings is not so obvious.[6] The reasons for this will become evident by comparing the pictures in Figures 46 and 47. The picture in Fig. 46 shows a conventional horizontal wire dipole antenna which is mounted on to the glass window panes in Room 4D423 in the Hexagon building. This dipole is made from and connected with a 300 Ohm twin wire line to the antenna terminals of a PRC-74 set. Thanks to the variable output impedance of the PRC-74, the window dipole could be matched to the set within a narrow frequency range at around 11.950 MHz. The picture in Figure 47 shows the same windows with their metal frame coupled to another PRC-74 radio set via a short piece of RG-58 cable and the match box and HEMAC circuit. The relative performance of the window dipole and of the HEMAC coupled window frame as an RF antenna was measured in two ways:

(a) On March 16th, 1973 the levels of the emitted 11.950 MHz CW and voice signals were compared as received at station AD2XL in the Evans area from the window dipole and from the HEMAC coupled window frame powered from the PRC-74 sets, with respectively 11.5 and 12.0 watts RF power. Before 1100 hours local time the signal plus noise to noise ratios received at the Evans station from the window dipole and from the HEMAC coupled window frame were 20 dB/15 dB and 25 dB/15 dB. After 1100 hours broadcasts from BBC London, England interfered with further measurements on this frequency, i.e., the optimum frequency for the window dipole and subsequent transmissions to the Evans station were carried out on 11.938 MHz.

On the previous day, the 15th of March 1973, similar transmissions from the HEMAC coupled window frame to Evans were made with the HEMAC coupled to the upper and the lower part of the window frame at various frequencies between 8 and 12 MHz. In spite of the dense occupancy of this frequency band by powerful HF stations from all over the world, signal plus noise to noise ratios could be measured on 10.540 MHz with maximal 18 dB/10 dB and minimal 22 dB/18 dB at different times of the day. The latter value reflects not only higher RFI noise levels but also a lower RF power output from the PRC-74 set as its battery power dropped towards the end of the transmission tests. Furthermore, voice transmissions on 11.800 MHz and 8.850 MHz were received intelligibly in the presence of strong RFI.

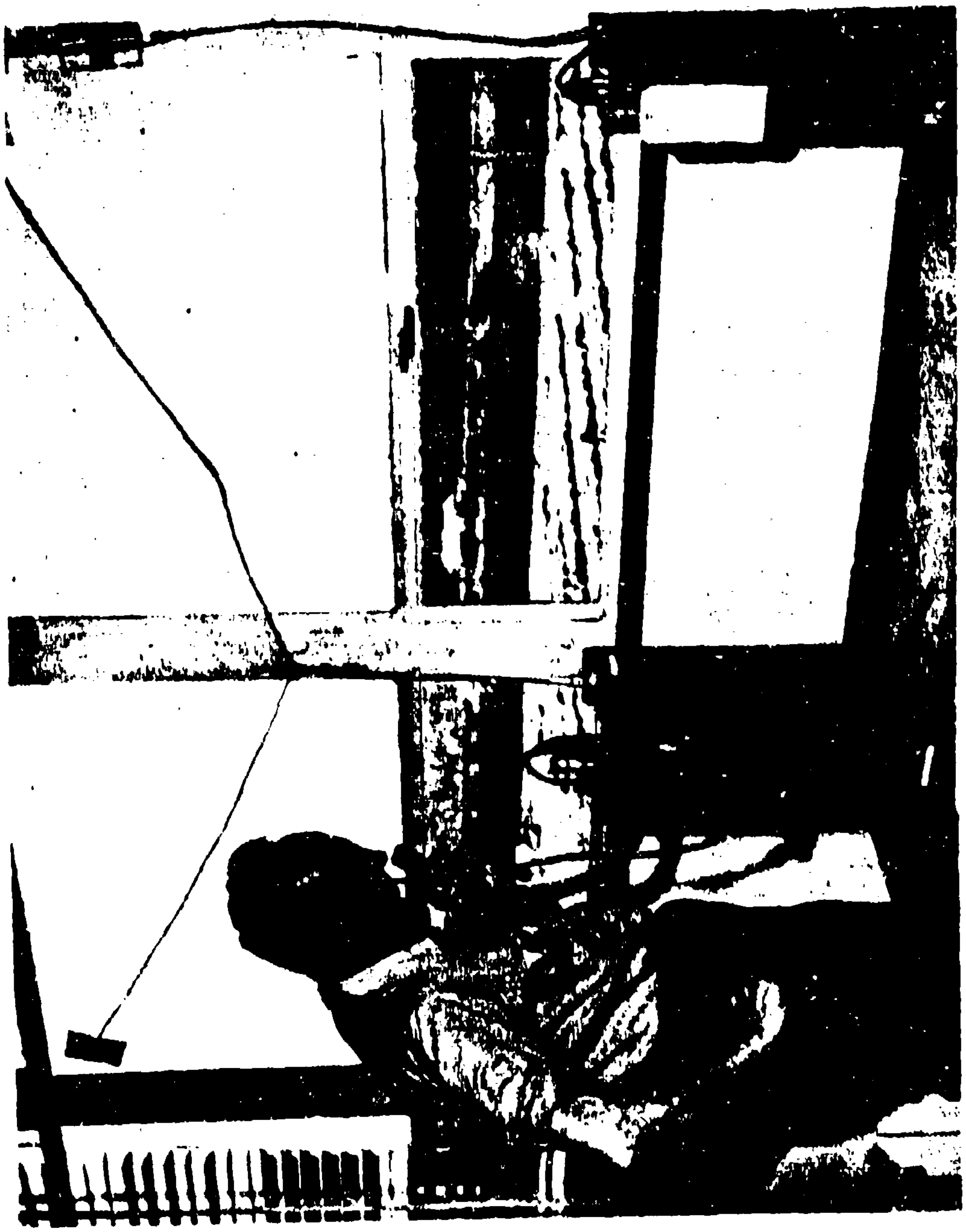


Fig. 46 Window Dipole (11.950 MHz Transmission Hex to Evans, Freehold, Oceanport, Hexagon (Room 4D323) April 1973

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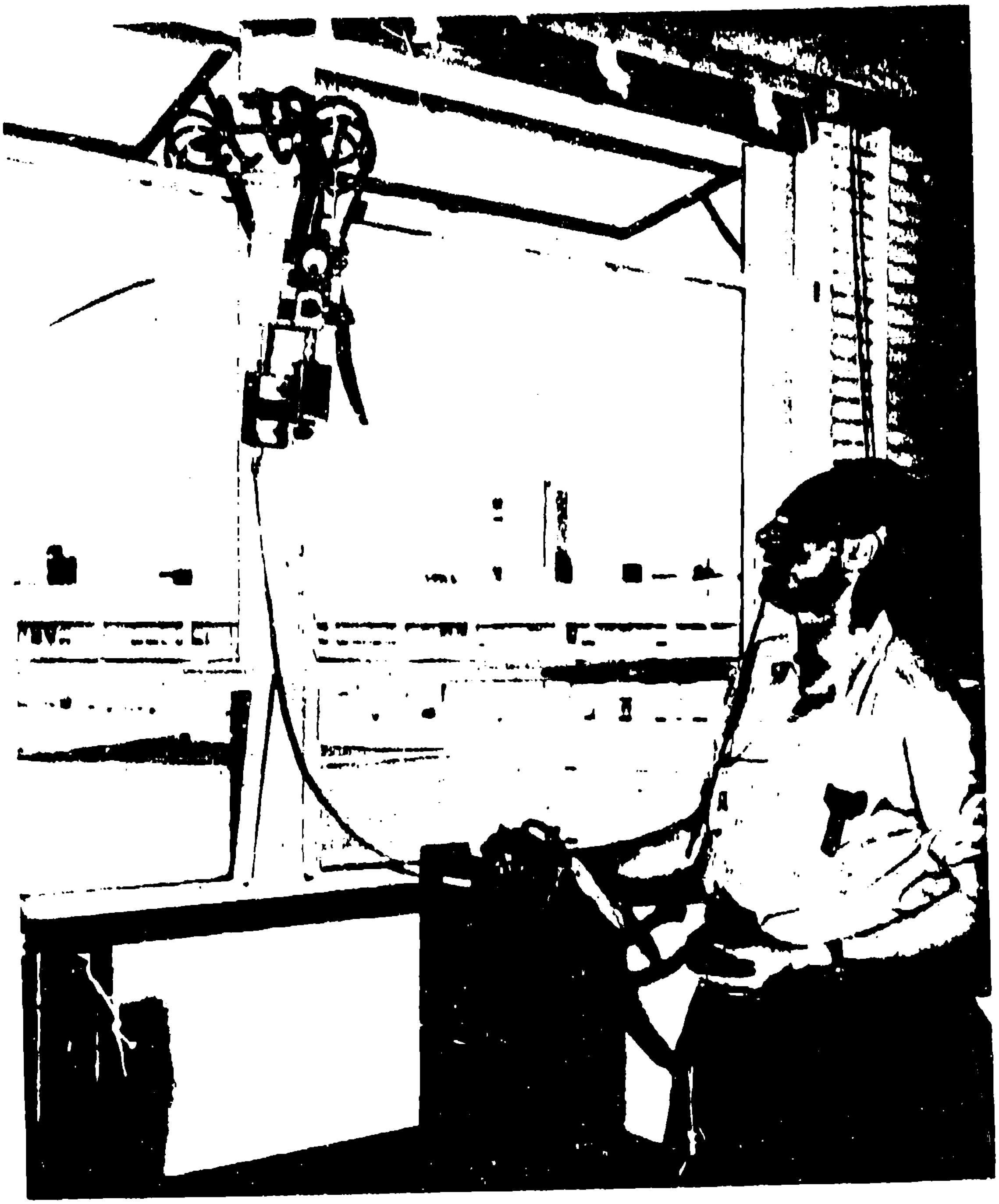

Fig. 47 HEMAC Coupled Window Frame (11.950 MHz Transmission Hex to Evans, Freehold, Oceanport, Hexagon Room 4D323) April 1973

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(b) On 13, 16, and 17 April 1973 voice communications range tests were made with the driver of a truck vehicle who had the whip of his PRC-74 set sticking out through the open window of the driver's cabin. These voice communications range tests were made in the western direction towards Freehold, N.J., and in the eastern direction towards Oceanport, N.J. for the following reason: The windows of Room 4D423 are on the western side of the Hexagon building and look into the yard which is open towards the west and bounded in the north, east and south by the completed parts of the building. On 13 April 1973, an exploratory range test with the HEMAC coupled window frame as antenna was made initially on 11.950 MHz.

However, during the test, at 1500 hours local time, the West African Service of Radio Hilversum, Netherland began to interfere strongly with the test frequency. Switching consequently to 11.970 MHz, a clearly intelligible voice communications range of 6.5 miles west from the Hexagon to the intersection of Highway 537 with Five Point Mile Road was obtained.

On 16 April 1973, a communications range - comparison test was carried out for the window dipole and for the HEMAC coupled window frame on 11.960 MHz. The results of this range test towards the east of the Hexagon, the direction blocked by the building, is tabulated.

16 April 1973 Test Data:

Window Dipole versus HEMAC-Window Frame XMTR

Mobile Station		Hexagon Station Rm. 4D423	
Air Mileage from Hexagon	Location	Window Dipole	HEMAC-Window Frame
2.0	Ft. Monmouth	Weak but readable	Loud & clear
3.5	Oceanport Post Office	Out, covered up by noise	Weak but intelligible

As pointed out before, RFI from powerful HF radio broadcast and commercial stations becomes very severe in the afternoon hours; similarly RFI in the Hexagon building, particularly from the freight elevator next to Room 4D423 tends to be higher and more frequent around noon and afternoon. For this reason the subsequent 17 April test runs east and west from the Hexagon were made in the morning hours on 11.950 MHz. The results are shown on the following page.

17 April 1973 Test Data:

Quality of Voice Transmissions from Window Dipole
HEMAC-Window Frame

Mobile Station		Hexagon Station Rm. 4D423	
Air Mileage East from Hex.	Location	Window Dipole	HEMAC-Window Frame
2.0	Ft. Monmouth	Clear	Clear
3.5	Oceanport Post Office	Clear	Clear, stronger
West from Hex.			
3.0	Intersection Hwy 537 Laird Road	Clear	Clear, stronger
4.3	Intersection Hwy 537 and 34 (*)	Readable OK	Readable OK
6.5	Intersection Hwy 537 and 5 Pt. Rd.	Much weaker but readable	Clear, strong
8.5	Hwy 537 approach to Freehold (*)	Readable	Weaker, readable

(*) = Power-telephone lines overhead

The observation that voice transmissions from the Hexagon window dipole were received slightly stronger than from the HEMAC coupled window frame when the receiver vehicle was parked directly beneath telephone and power lines deserves closer scrutiny with regard to the roles of polarization of the emitted RF fields. However, the tests prove beyond any doubt that the HEMAC coupled window frame is a highly efficient, unusual, and practically invisible XMTR and receiver antenna which can be tuned over a relatively large frequency range and that the structure and geometry of the building gives directivity to HF radiation from its windows.

The test results prove, furthermore, that RFI noise polluted building structures can be used effectively for the reception of relatively weak HF signals from the PRC-74 whip set in the vehicle in the Ft. Monmouth - Oceanport and Freehold, N.J. area and from HF radio stations overseas.

Considering this performance as HF antennas of building structures, it becomes an obvious challenge to apply whole buildings for the transmission and reception of such low frequencies and corresponding earth, water, and "urban jungle" penetrating long radio waves for which the size of conventional

antennas becomes prohibitive and on which man made and natural RFI noise too excessive for conventional means and methods of RF communications. In this connection it becomes necessary to mention the transmission of inductively emitted and received LF signals along the Earle to Sandy Hook, N.J. US Navy Railroad,[7] and subsequent transmissions over 20 miles along the Eatontown-Lakewood spur of the N.J. Central Railroad over a distance of 20 miles, from the Charles Wood-Ft. Monmouth area to Whiting, N.J. In both cases the maximal available RF-XMTR output was about 50 watts. During the measurements of the signal decay with distance along the railroad tracks it becomes evident that in addition to LF signal ducting along the railroad tracks, radiation directly from the railroad tracks and or indirectly from adjacent power and telephone lines must be involved. The subsequently described experiments were designed to further exploit both of these transmission mechanisms for clandestine type communications in urban jungles.

(2) <u>LF Signal Emanation and Reception via Urban Media.</u>

The transmitter for this purpose is shown in Figures 48 to 50. Fig. 48 shows the large RF solenoid wound on a fiberglas tube which is mounted horizontally on the roof of a M-109 trunk. This solenoid is powered by a nominal 50 watt Kronhite Amplifier driven from an XTAL controlled frequency synthesizer LF source. The picture in Fig. 49 shows the RF meter and capacitive tuning circuit encased in a lucite box inside the truck and the power amplifier circuit and output transformer on the shelf in the left upper corner of the picture. (The large "CML" generators beneath the lucite meter - tuning box were not used in these experiments). The emitted LF, CW and keyed CW signals were monitored in the truck with a scope. For this purpose they were picked up with a small ferrite loop stick which is seen mounted vertically in front of the window.

The picture in Fig. 50 shows the XMTR truck beneath a power line in the Camp Charles Wood Motor Pool yard, 1400 feet east of the Hexagon building, i.e., at location 1 in the map in Fig. 51. During the first test on 29 Jan. 1973, signals transmitted on 85.2 kHz from the XMTR-truck located under the power line in the Charles Wood Motor Pool area were received so strongly by the LF-VLF station in the Hexagon, that the primary XMTR power had to be reduced to approximately 30 watts. The transmissions were continued at the lower power level until 31 Jan. 1973. Until 0930 hours local time of this day, the 82.5 kHz emission as received, recorded by the LF-VLF station in the Hexagon building, was essentially stable. After 0930 hours, strong amplitude fluctuations set in with periods of approximately five minutes. The transmissions were then terminated at 1600 hours since no apparent reason for these fluctuations could be found and because of possible risks of continuing the transmissions unattended over the holidays. The transmission tests were resumed on 8 Feb. under stable conditions. On 12 Feb., at about 1400 local time (1900 GMT), the XMTR was disconnected from the commercial AC power supply and switched to a gasoline driven AC generator. Subsequently, the XMTR truck was moved from the motor pool location to ECOM's new "Green Acres" office building on the western side of the Garden State Parkway and about ½ mile west from the Hexagon building.

On the way to the Green Acres building, an intermediate stop-over was made on the parking lot north of the Hexagon, approximately 300 feet

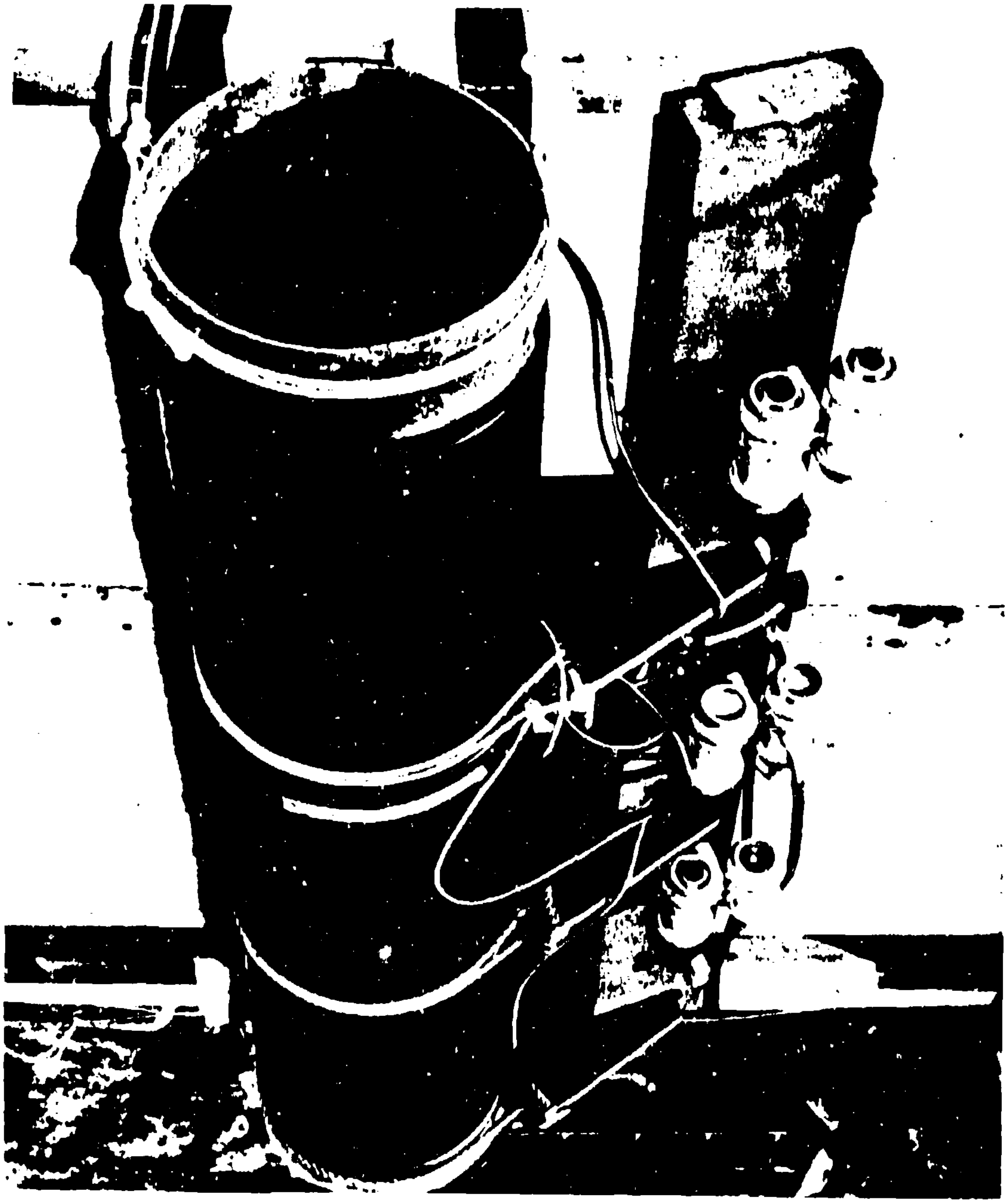

Fig. 48 LF - XMTR Solenoid on M-109 Truck Roof

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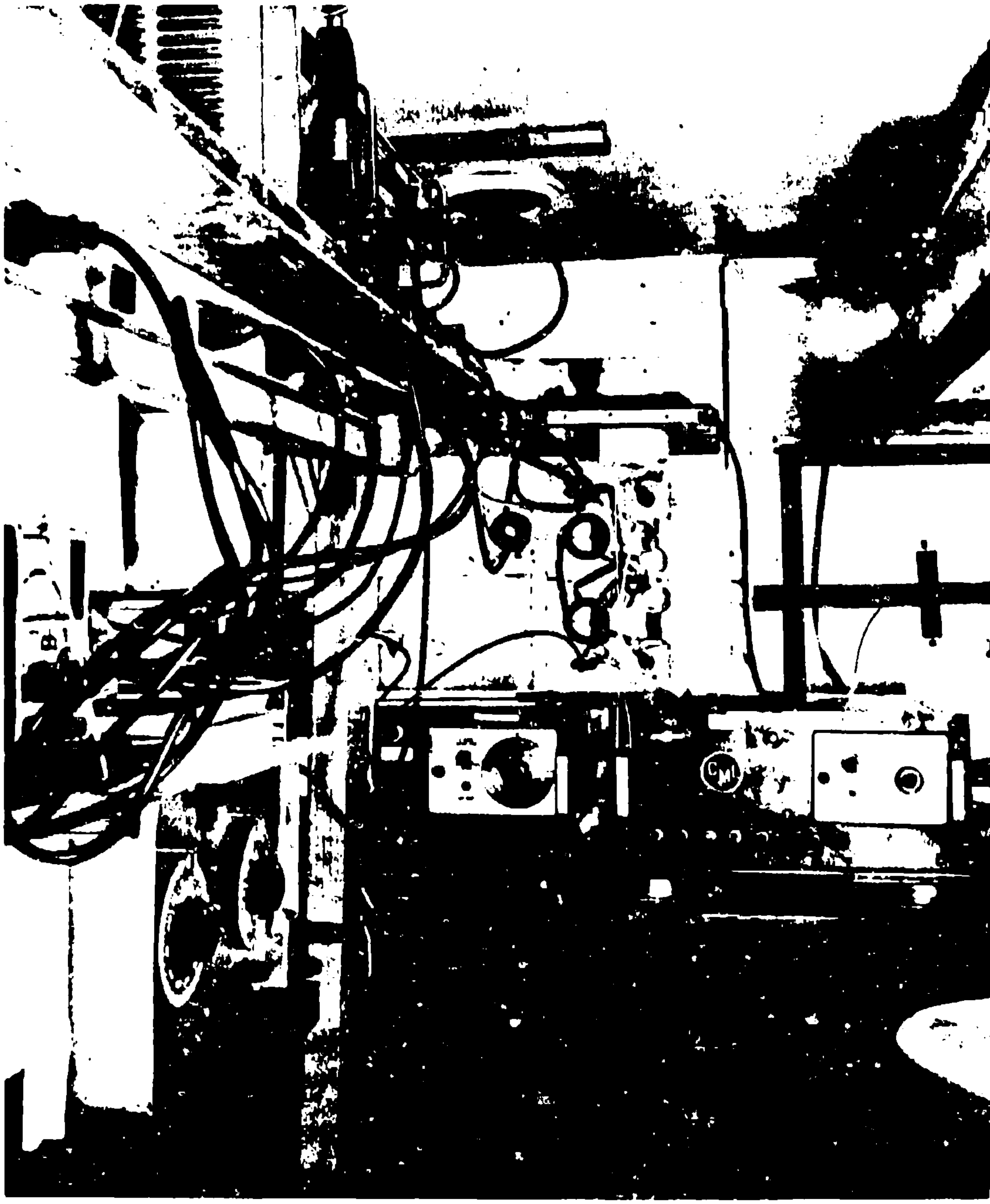

Fig. 49 LF - XMTR Setup in M-109 Truck Van

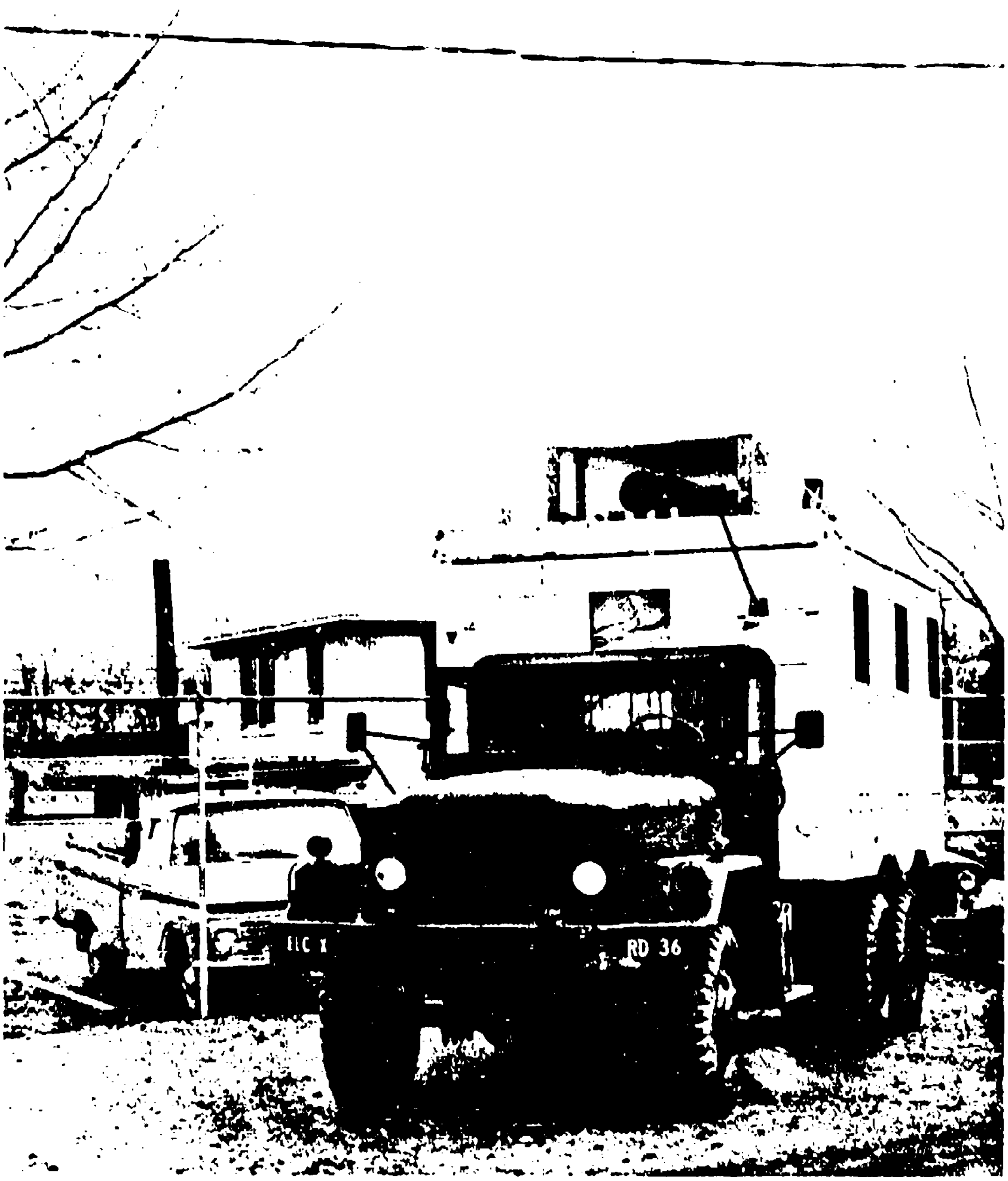

Fig. 50 LF-XMTR Truck Under Power Line at Camp Charles Wood Motor Pool (Location #1 for 85.2 kHz Transmission Test)
12 Feb. 1973

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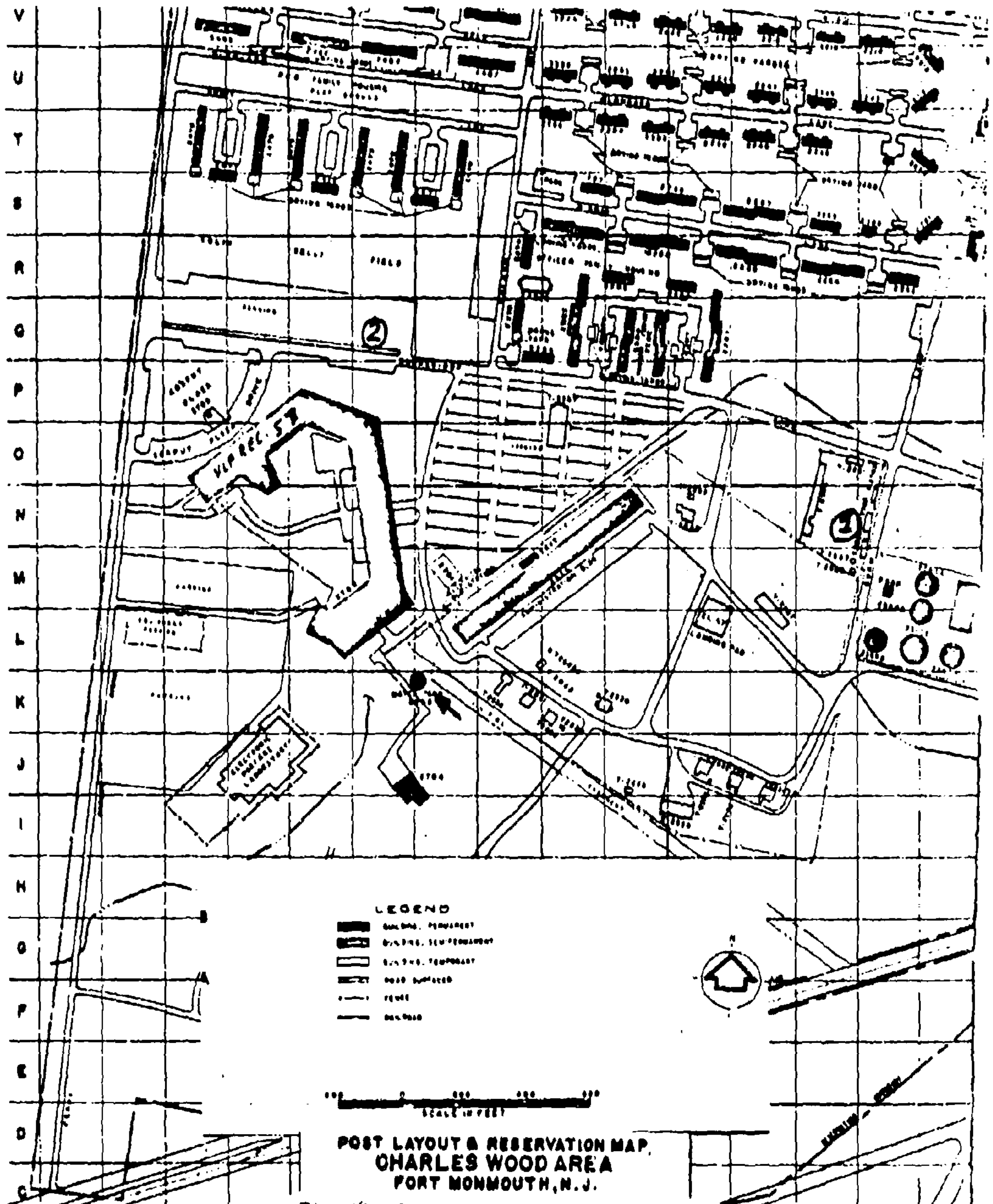

Fig. 51 Map - Hexagon LF-VLF Receiver Station and LF-XMTR Truck Locations #1 and #2 (85.2 kHz Transmission Test) 12 Feb. 1973

from the north side wall of the Hexagon, at location 2 in the map in Fig. 51. In contrast to the XMTR truck position at the Hexagon, a special effort was made at the Green Acres building to park the XMTR truck within approximately 10 feet distance from the aluminum panel walls of the building such that the XMTR solenoid was parallel to the walls. At the Green Acres site, the truck was first positioned on the south side of the building's wing which projects towards the east. Then the XMTR truck was positioned at the northern side of the Green Acres building, such that the building blocked the line-of-sight path towards the Hexagon. This position of the XMTR truck is shown in the picture in Fig. 52. CW signal transmissions from these four locations, at the motor pool, on the north parking lot of the Hexagon and on the south and north side walls of the Green Acres building were received via horizontal wire antenna on the Hexagon roof and recorded at the Hexagon LF-VLF Station. The received 82.5 kHz signal levels, as functions of time (GMT), and corresponding XMTR locations are shown in Fig. 53. Comparing the received signal levels and the corresponding transmitter to receiver distances involved, it is evident that the metal structure of the Green Acres building enhanced radiation of the LF signal stronger than the overhead power line at the motor pool location; variations of signal level, during the time of transmission from the respective XMTR locations, are largely due to the AC drift of AC primary power output from the gasoline driven AC generator.

Further evidence of the support role for LF communications of urban media is shown in Figs. 5. and 55. Here LF signals are received with an HRO-500 National Radio Receiver using ferrite loopsticks to pick up these signals from a water fountain and a heating radiator inside the Hexagon building. In contrast to the previously discussed transmissions on the XTAL controlled frequency of 85.2 kHz, the exact transmission frequencies were in these Nov. 72 tests dependent on the location of the XMTR truck and on its proximity to urban structures in its immediate environment, such as the water tower on the southeastern side of the Hexagon building, the support frame of the truck entrance and the yard-side walls of the Hexagon building (Map Fig. 51). At these locations the transmitted 80 to 90 kHz signal frequencies were generated by regenerative feedback obtained by connecting the output from the ferrite loopstick probe inside the truck (Fig. 49) to the input of the power amplifier circuit that feeds the XMTR solenoid on the roof of the truck (Fig. 48). Consequently, the EM coupling to adjacent secondary structures and the corresponding loading of the regenerative feedback circuit influences its frequency of oscillation. Observed frequency changes due to loading by "secondary structures" indicated that the coupling is not efficient, but results of the transmission experiments prove that the coupling is sufficient to pollute the Hexagon and parts of the adjacent Building 2525 by LF signals which are much stronger than the RF pollution from other sources including, in one case, an LF transmitter station of the US Navy.

3. SUMMARY AND CONCLUSION

A. Employing a phased twin tree array control over the directivity of HEMAC induced RF (4.650 MHz) radiation from large forest trees has been taken from the natural forest tree configurations and handed to the radio operator.

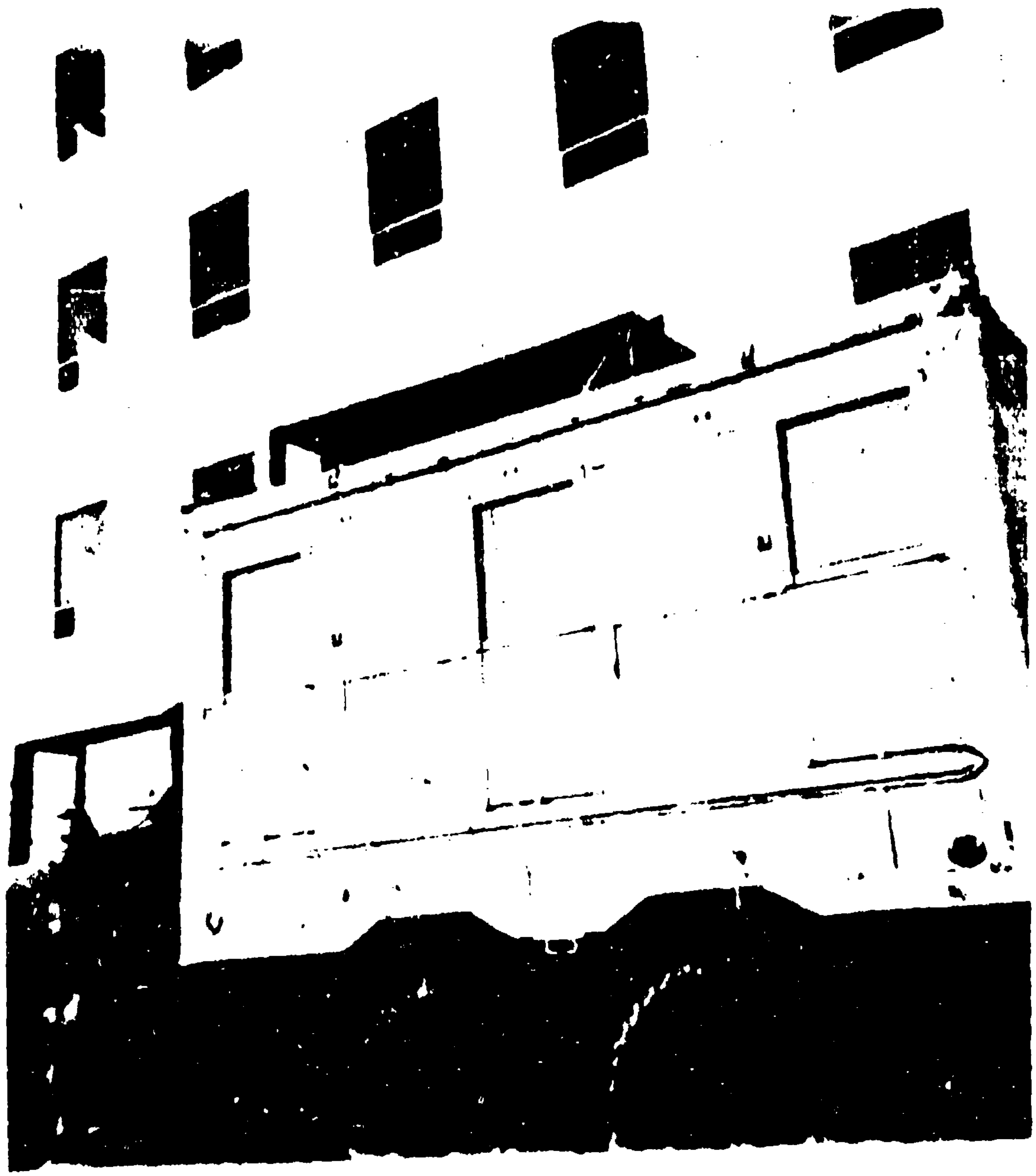

Fig. 52 LF-XMTR Truck at Green Acres Office Building (85.2 kHz Transmission Test)
12 Feb. 1973

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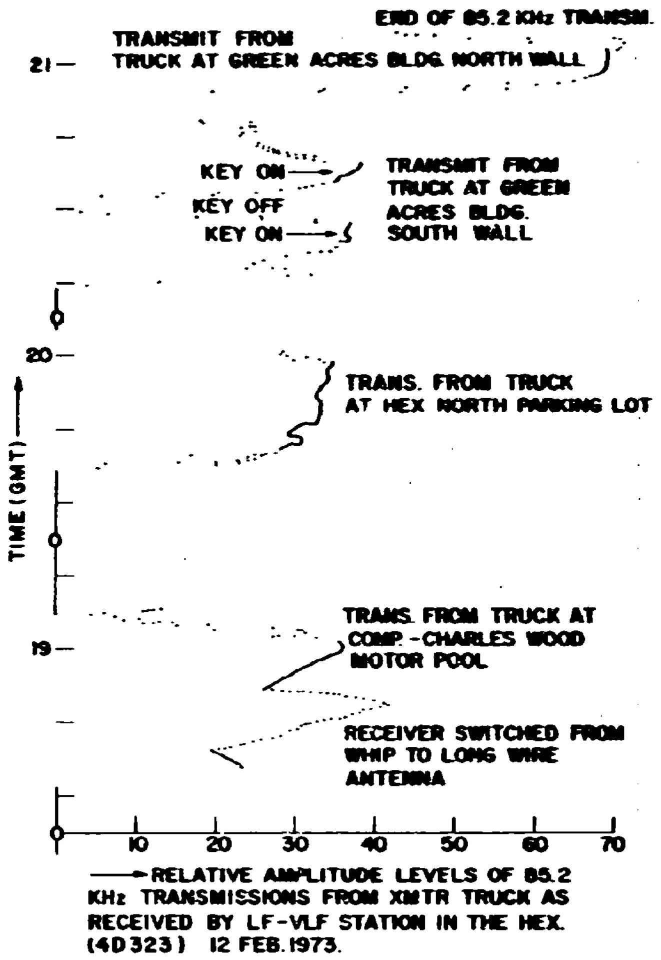

Fig. 53 Record of 85.2 kHz Signal Levels Received by LF-VLF Station in the Hexagon Building
12 Feb. 1973

Fig. 54 Pick-up by Ferrite Loopstick of 80 - 90 kHz Signals from Water Cooler in Hexagon Bldg.

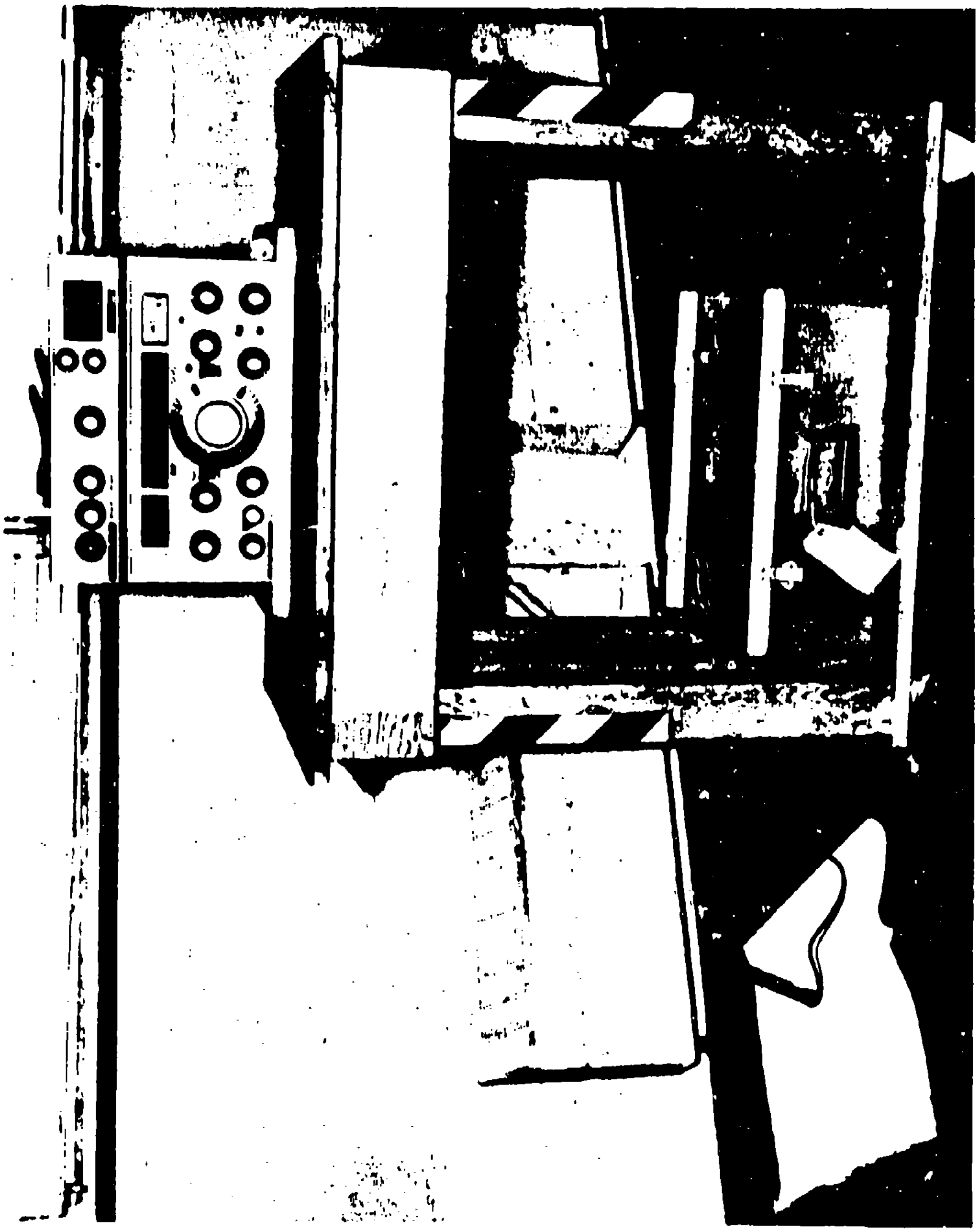

Fig. 55 Pick-up by Ferrite Loopstick of 80 - 90 kHz Signals from Heating Radiator in Hexagon Bldg.

B. The previously observed abrupt decays of radiation from different trees at frequencies between 7 and 11 MHz were found to be related to the occurrence of several resonances in the tree loaded HEMAC circuit.

C. Pursuing further the determination of practical upper frequency limits for the operation of trees as antennas, radiation measurements were made at frequencies between 5.5 MHz and 11.0 MHz.

In these measurements man-planted smaller shade trees and their neighboring urban jungle counterparts, i.e., metal lantern poles of comparable height, were put to work as HF radio antennas.

In ground to ground transmissions over 7 miles employing the PRC-74 radio transceiver and various smaller HEMAC's, the lantern poles outperformed the PRC-74 whip by 2 to 12 dB and the HEMAC's by themselves by 10 to 18 dB. The shade trees and the PRC-74 whip performed about equally well, with the tree yielding slightly better signal to noise ratios most of the time. Suspecting related differences in the ground and sky wave emission patterns, measurements were made of the RF output voltages from a HEMAC coupled lantern pole, a small shade tree, and the PRC-74 whip which were immersed into the RF field from an 8.25 MHz XTAL controlled test transmitter mounted in a gondola of an aerial tramway suspended above the respective receiver antennas. The recorded sharp null in the lantern pole output in contrast to the broad maximum of the tree output when the XMTR gondola moves over respectively the pole and the tree, indicate corresponding differences in their radiation patterns. Accordingly, ground and skywave emission seem to dominate RF radiation from the lantern pole and the tree. However, the actual spatial distribution of radiated sky and ground wave modes must be determined by radiation field pattern measurements by airplane. This is particularly true for the twin HEMAC coupled lantern pole case where a parasitic HEMAC circuit is used similarly as the center coil resonator of the PRC-74 whip to influence the RF current distribution along the lantern pole and thus its relative ground and sky wave emission ability.

D. The introduction of metal lantern poles as performance standards for trees of comparable height at higher frequencies opens the way for the exploitation of diverse structures and materials or urban jungles as antennas and RF transmission media.

The roles of buildings for these purposes were established at HF and LF frequencies. Between 8 and 12 MHz, evidence of the superior radiation abilities of HEMAC coupled metal window frames relative to a resonant dipole mounted across the window panes of the Hexagon building, was established by measurements at a fixed station 7 miles to the south and by communication range tests east and west from the Hexagon.

The resultant communications ranges 3.5 miles east and 8.5 miles west reveal the influence of the buildings' geometry on the directivity of HF radiation. Such directional phenomena were not observed in the diffusion of 82.5 kHz signals from ECOM's new Green Acres building to the Hexagon building and in the pollution of the water distribution system of the Hexagon

building with LF signals in the 70-90 kHz range. However, the LF diffusion and possibly secondary radiation enhancing role of buildings, has become evident as a result of these LF transmission experiments.

4. RECOMMENDATIONS

A. Incorporate into the planned measurements, by airplane, of the sky wave radiation from forest trees corresponding pattern measurements of the radiation from the lantern poles and from the window frame.

B. Perfect the method of coupling of RF power to and from structures and materials of urban jungles for their use as efficient and camouflaged radio antennas and transmission media.

C. Investigate the feasibility of clandestine communications in urban jungles by exploiting their RF pollution by friend or foe as transmission correlation references.

D. Apply the HEMAC methods and techniques to the exploitation of the super structures and the hulls of ships and planes as LF, MF and HF antennas.

5. ACKNOWLEDGMENTS

Research and development, leading to the exploitation as radio antennas of live vegetation in natural jungle environments, have been guided initially by Col. J. P. Dobbins during his tour of Duty as Director of ECOM's Communications/ADP Laboratory.

Col. J. D. Mitchell, the present Director of the Laboratory, is providing overall guidance and special technical advice for the application of HEMAC techniques to the exploitation as RF antennas and transmission media of diverse structures in man made urban jungle environments.

Mr. Richard Simmons, from ECOM's CSTA Laboratory, has assisted in the various transmission measurements from the Wayside and Hexagon areas to the Evans area radio station.

Mr. James Hargrave and SP5 Gerald D. Cook received and recorded at the Hexagon LF-VLF station the LF signal emissions from various locations in the Camp Charles Wood, Hexagon area, and the Green Acres area.

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13. ABSTRACT

Natural forest trees, man-planted shade trees, metal lantern poles and building structures were utilized as efficient HF radio antennas with the aid of Hybrid Electromagnetic Antenna Couplers (HEMAC's). The performance of live trees and of inanimate metal structures as antennas is compared with the performance of conventional HF whip and dipole antennas. Similar practical data are given on the LF radio signal emission capabilities of huge steel-concrete buildings and on LF radio signal diffusion via electrical power and water distribution systems in suburban areas.

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